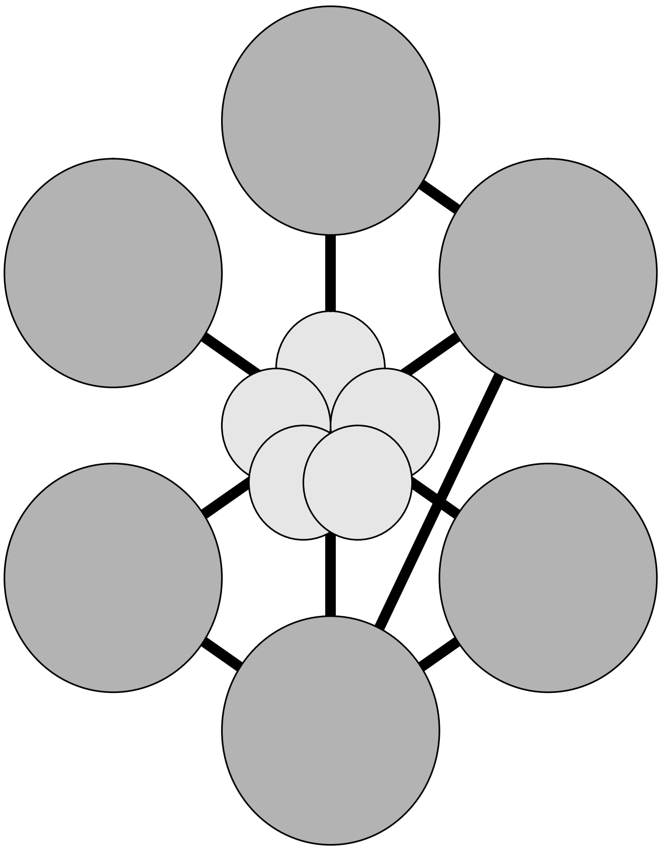

CASTEM2000

USER'S GUIDE

NOVEMBER 1993

PREFACE

This manual of CASTEM2000 is composed of two parts :

- the first part consists of a **user's manual** in which CASTEM2000 general principles as well as the proper way of performing the calculation of an elastic structure are described;

- the second part consists of a **training manual** which includes several lessons; it is meant to help the beginners' first steps.

There are essential additional pieces :

- a **collection of annotated examples**, classified by subject.

- a **reference manual** in which the functions and the way to use each operator, directive and procedure are described.

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1 st PART

USER’S MANUAL

FOREWORD

NOTATION

The symbols used mainly in this manual are given below. The other symbols and notations are defined when they are used.

General conventions

Each matrix is symbolized by a capital letter underlined with a bold single line. Vectors are referred to by underlined small letters. The ^{T} exponent refers to a transposition whereas $^{-1}$ is used to refer to an inverse matrix.

Examples :

$\underline{\mathbf{A}}$	square or rectangular matrix.
$\underline{b}$	vector
$\underline{\mathbf{A}}^{-1}$	inverse matrix
$\underline{\mathbf{A}}^{T}$	transposed matrix

Symbols used

$\underline{\mathbf{B}}$	matrix of congruence connecting strains and displacements
$\underline{\mathbf{C}}$	damping or boundary conditions matrix
d.d.l	degrees of freedom
$\underline{u}$	vector of nodal displacements

E	modulus of elasticity
$\underline{\mathbf{D}}$	Hooke’s matrix
$\underline{b}$	force by unit of volume
G	shear modulus
$\underline{\mathbf{I}}$	identity matrix
$\underline{\mathbf{K}}$	stiffness matrix
$\underline{\mathbf{M}}$	mass matrix
M,N	bending moment, membrane effort
$\underline{\mathbf{N}}$	matrix of shape functions
$\underline{f}$	vector of nodal equivalent loadings
f	frequency
T	temperature or shear force
t	time
s	thickness
S	surface

V	volume
u,v,w	displacement components
g	acceleration of gravity
$\underline{\mathbf{0}}$,0	null matrix and vector
α	thermal expansion coefficient
Δ	finite increment
δ	virtual operator
$\underline{\varepsilon}$	strain vector
Θ	angle or polar coordinate
$\underline{\lambda}$	vector of Lagrangian multipliers or eigenvalues
ν	Poisson’s ratio
ρ	mass density
$\underline{\sigma}$	stress vector
ω	pulsation

UNITS OF MEASUREMENT

CASTEM2000 does not have any special system of units of measurement: it is up to the user to supply the data to be integrated to a system with appropriate dimensions while defining the model.

The system coherence will be checked by applying the basic law of dynamics according to which:

$$F=m\gamma$$

Once the units of measurement used in the data are defined, all the results will be expressed with these units.

However, there is an exception to this rule: the measurement of angles must always be expressed in **degrees**.

On the other hand, both the values of temperature and the thermal expansion coefficient must be expressed with coherent units.

A few examples of appropriate systems of units of measurement as well as steel characteristic values for density and Young's modulus are gathered in the following table:

Length	**Mass**	**Force**	**Density**	**Young's modulus**
m	kg	N	$7.85\ 10^{3}$	$2\ 10^{11}$
m	10^{3} kg	10^{3} N	7.85	$2\ 10^{8}$
cm	kg	10^{-2} N	$7.85\ 10^{-3}$	$2\ 10^{9}$
cm	10^{3} kg	10 N	$7.85\ 10^{-6}$	$2\ 10^{6}$
mm	kg	10^{-3} N	$7.85\ 10^{-6}$	$2\ 10^{8}$
mm	10^{3} kg	N	$7.85\ 10^{-9}$	$2\ 10^{5}$
cm	10^{2} kg	N	$7.85\ 10^{-5}$	$2\ 10^{7}$
m	10^{4} kg	10^{4} N	$7.85\ 10^{-1}$	$2\ 10^{7}$
cm	10^{6} kg	10^{4} N	$7.85\ 10^{-9}$	$2\ 10^{3}$
mm	10^{7} kg	10^{4} N	$7.85\ 10^{-13}$	$2\ 10^{1}$
m	10 kg	10 N	$7.85\ 10^{-2}$	$2\ 10^{10}$
cm	10^{3} kg	10 N	$7.85\ 10^{-6}$	$2\ 10^{6}$
mm	10^{4} kg	10 N	$7.85\ 10^{-10}$	$2\ 10^{4}$

References

[1] P . Verpeaux, A . Millard,

“ Quelques considérations sur le développement de grands codes de calcul “

Report DEMT 88/179

[2] M.F . Robeau, P . Verpeaux,

“ Langage de données Gibiane 77 “

Report DEMT 86/80

1. Introduction

CASTEM2000 is a computer code for structure analysis by the finite element method (F.E.). This code was originally developed by the “Département des Etudes Mécaniques et Thermiques (DEMT)” (Department of Mechanical and Thermal Research) of the French “Commissariat à l’Energie Atomique (CEA) (Nuclear Energy Agency, equivalent to the British AEA).

The development of CASTEM2000 is part of a program of research in the field of mechanical engineering; it aims at defining an advanced tool to be used as a proper support for the design, resistance-evaluation, and analysis of structures and components in both the nuclear and any other industrial areas.

From this point of view, CASTEM2000 offers a complete system: not only does it integrate computer functions proper, but also functions for the model construction (preprocessor), and result processing (postprocessor).

In the current version of CASTEM2000, the manual covers only the part of it that deals with problems of linear elasticity in static and dynamic areas (extraction of eigenvalues). CASTEM2000 also enables the user to deal with thermal problems, non linear problems, (elasto-visco-plasticity), step-by-step dynamic problems, etc.

2. General remarks concerning CASTEM2000

This computer code has the following distinctive feature: it enables the user to personalize and complete the available system so as to adapt it to his own requirements; moreover, the program total flexibility facilitates the resolution of problems. Unlike other systems designed to solve specific problems to which the user must submit, CASTEM2000 is a program that the user can adapt to his own needs.

In practise, the program is composed of a series of operators; each operator can only execute one operation. The user only has to call on any operator by means of the appropriate instruction to have it executed; as a result, the user can define or adapt the sequence of resolution to any problem.

The language used to define the processing functional instructions is advanced: GIBIANE is especially useful insofar as it favours data exchanges between user and program.

In spite of the program large flexibility, the user still needs to learn to formulate his calculation problems according to the method adopted by the code. As a result, it is important for him to understand how a finite element analysis is structured and organized, so as to be able to establish a direct connection between the mathematical or logical operation to be formulated and the operators to be used.

2.1. Organization of the F.E. calculation process

Any generic analysis carried out by the finite element method can be divided into 3 successive stages. Likewise, each stage can be subdivided into a series of elementary processes [1].

The stages in question can be described as follows:

- ***STAGE 1. DEFINITION OF THE MATHEMATICAL MODEL:***
  - geometrical discretization of the studied region;
  - definition of data featuring the model. They include: the type of analysis (plane strains or stresses, axisymmetry, etc.), the type of element (beam, shell, etc.), the material properties, the geometrical characteristics that cannot be infered from the meshes and the boundary conditions.
- ***STAGE 2. RESOLUTION OF THE DISCRETIZED PROBLEM***
- ***calculation of mass and stiffness matrices for each finite element;***
  - assembly of the stiffness and mass matrices of the complete structure;
  - application of external loadings;
  - application of boundary conditions;
  - resolution of the system of linear equilibrium equations
- ***STAGE 3 . ANALYSIS AND POSTPROCESSING OF RESULTS that can either be local quantities such as displacements, stresses, strains, or global quantities such as strain energy, or else maximum strain.***

Usual computer programs are rigorously structured according to this logic, each stage being associated with a definite modulus specific to the code:

- 1) a preprocessor for defining the complete model which transmits the data to the computer program proper, as soon as the data are elaborated;
- 2) the computer program which sends a series of processes which the user is compelled to use in “black box” as soon as a procedure of resolution has been selected;
- 3) a postprocessor which carries out the required processings as soon as it has received the results from the above processes.

It is obvious that the user does not have to intervene with this type of structure in any of the stages to bring about modifications meeting his own needs. However, more flexibility would be of benefit to the user who sets out to solve various problems located at different points of the resolution process.

The user could indeed come up against great difficulties when modeling the structure geometry usually composed of several complex parts, in a way best suited to the requirements of the analysis.

Besides, the process of discretization requires that the elements be distributed in a specific way: in order that the costs for analysis be profitable as much as possible, it is advisable to concentrate the elements in the regions liable to undergo sudden variations in the unknown function and, on the contrary, to avoid storing them in regions of minor interest.

Gathering several different mathemetical formulations (beams, shells, solids...) relating to several parts of the structure, i.e. making them compatible within a same structure, or defining particular types of boundary conditions or loadings may sometimes seem extremely difficult.

Within the framework of an analysis, it might thus be interesting to be able to define, step by step, the most adequate sequence of elementary processes of the different stages by joining them and by supplying the requested data at each new step.

2.2. CASTEM2000 distinctive features

The CASTEM2000 system has been designed and developed to be more flexible than the conventional codes.

As a result, the user, among other things, has the GIBIANE macrolanguage at his disposal which enables him to define easily each operation of the different stages of analysis, by means of extremely simple instructions [2].

The structural stress calculation from displacements can, for instance, be performed either directly by means of a single instruction ($\underline{u} \rightarrow \underline{\sigma}$) when both the geometrical and material characteristics or the displacements are known, or by means of several successive instructions enabling the computation of the strain vector at first $\underline{\varepsilon}=\underline{\mathbf{B}}\ \underline{u}$ followed by that of the $\underline{\mathbf{D}}$ elasticity matrix and finally by the product $\underline{\sigma}=\underline{\mathbf{D}}\ \underline{\varepsilon}$.

These operations are performed on objects which will stand for the complete structure to be studied or each of its elementary components when necessary.

All this is now possible with the uncommon data base management system which has been created in the program. From now on, the data of the problem, whether mechanical properties of the material, or geometrical characteristics of the created mesh, or else force fields or stresses, etc. can be handled easily by referring to the names chosen and attributed by the user himself.

A piece of information or a set of information makes up what is called an OBJECT in the program.

Besides the fact that they are named by the user, which enables him to find them, all the objects have a specific type, which enables him to find the structure of data associated with them. Some objects can be of ENTIER (integer) or FLOTTANT (real) type and are characterized by a very simple structure; others such as those of MMODEL type will be more complex: they contain the reference to the structure geometry, the formulation of the relative finite elements, or the material behavior.

What matters most to the user is the name, the type is above all a computer requirement which allows, however, the syntax of data to be checked.

2.3. CASTEM2000 language: GIBIANE

GIBIANE is an advanced language enabling the user to communicate directly with the program through data exchange. All the operations performed with GIBIANE consist in handling existing objects with a view to modifying them or creating new ones.

The syntax of an elementary operation can require several objects; it takes various forms depending on whether the result obtained consists of one or several modified objects or of newly created ones.

In the first case, the instruction is as follows:

OPERAND DIRECTIVES;

“ELIM 0.001 GEOM ;” for instance, in which (ELIM) DIRECTIVE refers to the name of the function to be run and OPERANDS (GEOM 0.001) to the objects to be used.

In the second case, the instruction is as follows:

RESULTS=OPERANDS OPERATOR;

“LIGNE = DROI P1 P2 S ;” for instance, in which “OPERATOR” (DROI) refers to the name of the function to be run, “OPERANDS” (P1 P2 S) stands for the objects supplied as arguments in the operator syntax, and “RESULTS” (LIGNE) refers to the objects resulting from the operation.

Operations are performed by operators which apply directly to objects supplied as arguments. Operands can be already existing objects containing information characteristic of the analysis to be carried out, or specific objects defined only to facilitate the execution of the requested operation.

Allocating a name to an integer or a real number (**PAR = 12, PI = 3.14**) makes it possible to generate the corresponding ENTIER and FLOTTANT type objects that will be used to perform algebraic operations with other objects (multiplication, division, etc.)

The operations performed on objects lead to the creation of new objects which may have the same type as operands. As a result, the algebraic type operators such as +, -, *, / or the ET operator which combines two or several objects are usually used for the creation of new objects of same type as the initial objects.

More sophisticated operators, on the other hand, create objects of a different type. The MODL operator, for instance, uses a MAILLAGE (mesh) type object and MOT (word) type objects for the creation of a MMODEL type object containing the references to the geometry, the finite element formulation, the material behavior of the analyzed structure.

2.4. CASTEM2000 potentialities

2.4.1 Notion of procedure

The structure adopted in CASTEM2000 is above all useful for the elaboration of **procedures** which are, as it were, **upper level operators**; these procedures call on in turn a series of **elementary operators**.

These procedures have been created to meet various requirements:

- first, it is possible to use the same data for several operators, which allows them to be gathered and found easily by means of a single instruction.
- second, in the case of rather complex or repetitive problems, the user may find it difficult to explicitly define standardized operations every time.
- finally, people who are not familiar with the finite element method but use it all the same should like to go back to the program “black box” running. This would amount to hiding elementary procedures as a whole by means of a single procedure.

The procedures have the following characteristics:

- they can be used in the same way as elementary operators
- a procedure can call on other procedures and can call on itself
- a procedure can be composed of other procedures

- the sequence of elementary operators contained in a procedure is always visible.

All these characteristics enable the user to program by himself the processes required for solving his own problems.

In addition, he can write and test new algorithms fastly, without having to face the difficulties tied to the programming itself.

2.4.2 Development of **new operators**

CASTEM2000 special structure not only enables the user to elaborate procedures capable of solving new types of problems, but also to define operators different from those in existence in exceptional cases.

The new operators can actually be developed, tuned up and checked apart from the others. One just needs to know the structure of the data contained in the objects handled by the new operator, and in the objects common to the whole program. This is especially useful when the analysis demands specific adaptations.

Of course, creating new operators implies that the developer masters ESOPE, the **programming** language which is a kind of highly efficient FORTRAN. Without going into details, the user just needs to specify that a computer entity such as a subprogram is written in ESOPE language, translated in standard FORTRAN, and compiled as usual.

To remove any ambiguity, it is advisable to distinguish between:

- the developer’s language	: ESOPE
- the user’s language	: GIBIANE

It is obvious that a user who writes procedures i.e. super-operators becomes a GIBIANE developer.

2.5. General aspects for using the program

CASTEM2000 can be used both in **interactive** or **batch** mode. The user should give preference to the mode which will enable him to make the most of the code, especially the user-program dialogue.

The running session is in any case fully memorized in a file which can be edited directly before being subjected to the program in the event of another execution.

The structure of this file is identical to that of the file containing all the controls required for a running in batch mode. The user may prepare those controls so that they apply to the definition of the model, to the running of the calculation and to the postprocessing of the results.

However, it would be better to proceed following several stages: prepare the data in interactive mode, perform the computation in batch mode, and then return to interactive mode for the postprocessing. It is actually a matter of performing several successive inputs and transmitting at each new stage the data resulting from the previous one.

For this purpose, there are objects for the management of operators which save both simply and fastly the data on a file (see user’s manual for using the SORT and SAUV operators) or retreive them for the next runnings (refer to manual concerning the LIRE and REST operators).

For interactive mode runnings, the user can also call on an “on-line help” which supplies some information about the operators. The directive is called INFO and is used as follows:

```
INFO ‘name of the operator’ ;
```

This directive makes it possible to generate instructions relating to all the operators and procedures of CASTEM2000.

2.6. General syntactic rules

List of the main syntactic rules to follow when using the GIBIANE language:

- The **blank**, **comma**, **equal** and **colon** characters are separating characters.

- The **semi-colon** ends an instruction.

- An instruction must not exceed **9 lines**, but a single line may contain several instructions.

- The GIBIANE interpreter does not take into account any line beginning by an asterisk in first column; as a result, the user can **annotate** his sets of data.

- Both the operators and the directives are defined by the first **four** characters, the next ones are not taken into account.

- An instruction is interpreted from left to right. Once the program has detected the name of an operator, it sends the monitoring progress to it.

- Only the first **72** characters of a line are taken into account.

- An instruction may contain brackets. In accordance with the rules of algebra, the instructions found in the inner brackets are executed before those in the outer brackets.

- The brackets are replaced with the result of their contents before the external instructions be interpreted. However, the user cannot have access to this result since no name has been allocated to it.

- The sign = enables the user to attribute a name to the result of the instruction.

- The name attributed cannot exceed **eight** characters.

- The program associates a type with each string encountered in a line.

- A MOT type object is a **72-**character string at most ranged in apostrophes.

- If the program detects a character string which cannot be interpreted as numerical value, it checks whether this string is the name of an object the type of which is already filed. If this is the case, it gives a type and a pointer to it; otherwise, it interprets it as a MOT type object.

- Finally, last recommandation to users: **try not to attribute the name of an already existing operator to an object**. For reasons of clarity and precision, an operator once defined again as a new object can no longer have its initial function in the sequence of data.

3. Structures, data and general operators

We have shown in chapter 2 that the whole computer structure of CASTEM2000 was based on the concept of objects, i.e. of data or information relating to each process.

Some special operators enable the direct construction of elementary objects. On the other hand, others are used for the construction of more complex objects, by modifying or associating one or several objects of elementary types.

All the existing general-type operators for the construction of complex objects are detailed further on in this chapter.

However, we suggest giving you now a classification of these objects to specify their potentialities and the rules for using each of them.

3.1. Classification of objects

The objects available in CASTEM2000, i.e. liable to be generated, handled or processed are ordered according to the type of data they contain and to the meaning they have in the analysis. Some of these objects contain data which are defined and memorized solely in relation to the operations to be run in the course of the process.

Here is the list of the main types of objects (one can easily obtain the type of each object by listing its contents using the LIST operator):

Object type	**Description**
AFFECTE	Object relating to the definition of the calculation model and containing the data relating to the discretized geometry, to the behavior model and to the finite element formulation which must be used. CAUTION: the AFFECTE type objects correspond to the former computer organization and **will no longer be used from the 93 Clients' version**.
ATTACHE	Object containing the description of the linkages between substructures with a view to dynamic analysis.
BASEMODA	Object containing the description of the linkages applying to a structure and the specification of all the modes and static solutions.
BLOQSTRU	Object containing the description of the linkages between substructures with a view to dynamic analysis.
FIELD BY ELEMENTS	Object containing any type of data defined in the elements: material characteristics, shell thicknesses, beam cross sections, stresses, etc. Each finite element can support several types of fields by elements; each field is characterized by a given number of components. In the current version of CASTEM2000, there are two types of objects enabling the description of a field by element: the **CHAMELEM** type objects that correspond to the former data computer organization and the **MCHAML** that correspond to the new organization. **From the 93 Clients' version, the operators only function with this structure.** It is possible to move from one type to the other by means of the CHAN operator.
CHPOINT (FIELD BY POINT)	Object containing any type of data defined at the temperature, displacements nodes...
CHARGEMENT(LOADING)	Object containing the time and space description of a loading.
CONFIGURATION	Object relating to the description of a discretization field.

DEFORME	Object relating to the characterization of a deformed region obtained by superimposing a MAILLAGE type object on a CHPOINT type object (field by points).
ELEMSTRU	Object allowing linkages to be written between substructures; it contains the description of an element of a structure with the associated geometry.
ENTIER (INTEGER)	Object composed only of an integer.
EVOLUTION	Object defining a graph.
FLOTTANT (REAL)	Object composed only of a real number.
LISTCHPO	Object composed of a list of CHPOINT.
LISTENTI	Object composed of a list of integers.
LISTMOTS	Object composed of a list of words.
LISTREEL	Object composed of a list of real numbers.
LOGIQUE (LOGICAL)	Object containing a logical variable with a true or false value.
MAILLAGE (MESH)	Object containing the topology of the discretized region.
MODELE	Object defining the material type of behavior. Since the data of the FIELD BY ELEMENT type objects have been reorganized, those of the MODELE type objects have also be revised. For the time being, there are two types of objects allowing the material behavior type to be described: **MODELE** associated with a **CHAMELEM** type field by element**,** **MMODEL** associated with an **MCHAML** type field by element.
MOT (WORD)	Object composed of one word.
POINT	Object defining the coordinates of a point and the associated density.
RIGIDITE (STIFFNESS)	Object containing the data relative to a stiffness or mass matrix.
SOLUTION	Object containing all the eigen vectors and values associated with a modal analysis.

STRUCTURE	Object connected with the description of a structure and containing the stiffness and mass related to it.
TABLE	Set of objects which can have any type and are characterized by any type of index.
VECTEUR (VECTOR)	Object relative to the display of a field by points by means of vectors.

3.2. Classification of CASTEM2000 main operators

Operators are grouped together according to their function: operators of general interest, operators used for the preparation of the model, operators used for solving the problem and postprocessing operators.

OPERATORS OF GENERAL INTEREST

Direct creation of objects:

- general type

COPI, EXIS, MANU

- fields (field by elements and field by points)

CHPO, HOOK, MOME, VARI, ZERO

- stiffness

AMOR, CABL, CAPA, COND, EXCI, LUMP, MASS, PERM, RELA, RIGI

- evolution

BRUI, EVOL, FDT, FILT, LAPL, MAPP

- objects relating to the substructuration

CHOC, CSLT, DEPB, DEVE, ELST, JONC, LIAI, RELA, STRU

- lists of objects (integers, real numbers, words, fields...)

LECT, MOTS, PROG, SUIT

- other objects (modal basis, table, configuration...)

BASE, FORM, MOT, SUPE, TABL, TEXT, VECT

Management of objects and memory :

ACQU, ARGU, DETR, INFO, LIRE, LIST, MENA, MESS, NOTI, OBTE, OUBL, PLAC, RESP, REST, SAUT, SAUV, SORT, TEMP

Execution of arithmetic operations :

+, -, * , / , **, ABS, ATG, COS, ENTI, EXP, FLOT, LOG, MULT, SIGN, SIN

Execution of logical operations :

< , <EG, > , >EG, EGA, EXIS, FINS, MULT, NEG, NON, OU, SI, SINO

Execution of mathematical operations :

COLI, COMB, CONC, ET, INTG, IPOL, NNOR, NORM, ORDO, ORTH, PMIX, PSCA, PVEC, RESU, SOMM, XTMX, XTX, XTY, YTMX

Retreival or processing of data in objects :

CMOY, COMT, COOR, DIAG, DIME, DIMN, EXCO, EXTR, INDE, MAX1, MINI NBEL, NBNO, QULX, TIRE, TYPE, VALE, VALP

Modification of data in objects :

CAPI, CHAM, CHAN, CHSP, ENLE, INSE, NOMC, PICA, PRCH, PRHC, REDU REMP, RIMP, RTEN, SAUF

Calculation of functions :

FONC, GREE, IFRE, TFR, TFRI

Loops, instructions with conditions and procedures :

DEBP, FIN, FINP, FINS, ITER, QUIT, REPE, RESP, SI, SINO

OPERATORS USED FOR THE PREPARATION OF THE CALCULATION MODEL

General parameters :

DENS, OPTI, TITR

Geometrical model :

- points

BARY, CONF, NOEU, POIN

- lines

CER3, CERC, COMP, CONG, COTE, COUR, CUBP, CUBT, DROI, INTE, PARA
QUEL

- surfaces

COUT, DALL, ENVE, FACE, GENE, REGL, ROTA, SURF, TRAN

- volumes

GENE, PAVE, VOLU

- colors

AFCO, COUL

- mesh processes

AFFI, CHAN, CONF, CONT, COOR, DEPL, DIFF, ELEM, ELIM, HOMO, INCL
INVE, MANU, MODI, MOIN, NBEL, NBNO, NOEU, ORIE, PLUS, POIN, PROJ
RACC, REGE, SYME, TASS, TOUR, VERS

Materials :

MATE, MATR, MODE, MODL

Displacement conditions:

ANTI, APPU, BLOQ, CONV, DEPI, FLUX, RELA, SOUR, SYMT

Loadings:

BSIG, CHAR, DEBI, FORC, MOME, PRES, SEIS, THET

Characteristics of elements and formulation :

AFFE (former elementary fields) , <u>CARA</u> , <u>CARB</u>

<u>OPERATORS USED FOR SOLVING THE DISCRETIZED PROBLEM</u>

ACTI, CRIT, DEVO, DSPR, DYNE, ELAS, EXCE, HOTA, KP, KSIG, KTAN MASS, MOTA, OSCI, PJBA, PLAS, PROI, PSMO, RECO, <u>RESO</u>, <u>RIGI</u>, SIGS, SPO SUPE, SYNT, VIBR

<u>OPERATORS USED FOR PROCESSING THE RESULTS</u>

Postprocessing operators :

DFOU, ENER, EPSI, GRAD, INVA, JACO, PRIN, REAC, RTEN, SIGM, SOLS TAGR, TOTE, TRES, VMIS

Operators used for graphic display :

DEFO, <u>DESS</u>, <u>TRAC</u>, VECT

4. <u>Preparation of the calculation model</u>

By computer model, we understand all the data that the user must prepare for describing in full the characteristics of the problem to be analyzed.

The calculation model is usually defined by:

- the general parameters defining the working medium and the basic characteristics of the global or local model on which one wishes to operate;

- the data describing, in discretized form, the geometry of the region to be analyzed;

- the characteristics of the materials composing the area of analysis;

- the boundary conditions expressed in terms of displacements imposed on the values of the unknown function and in terms of loadings and/or fluxes applied inside or outside the region examined;

- the type of formulation and the characteristics of the finite elements which are to be used.

Further down this writing, you will find a brief description of each data block. In annex B, all the operators involved in the preparation of the calculation model are arranged in alphabetical order.

Before proceeding, it is important to understand the logical stream of data and information used in CASTEM2000. One should not forget that in order to reach the resolution stage of the calculation, one needs the following data and information:

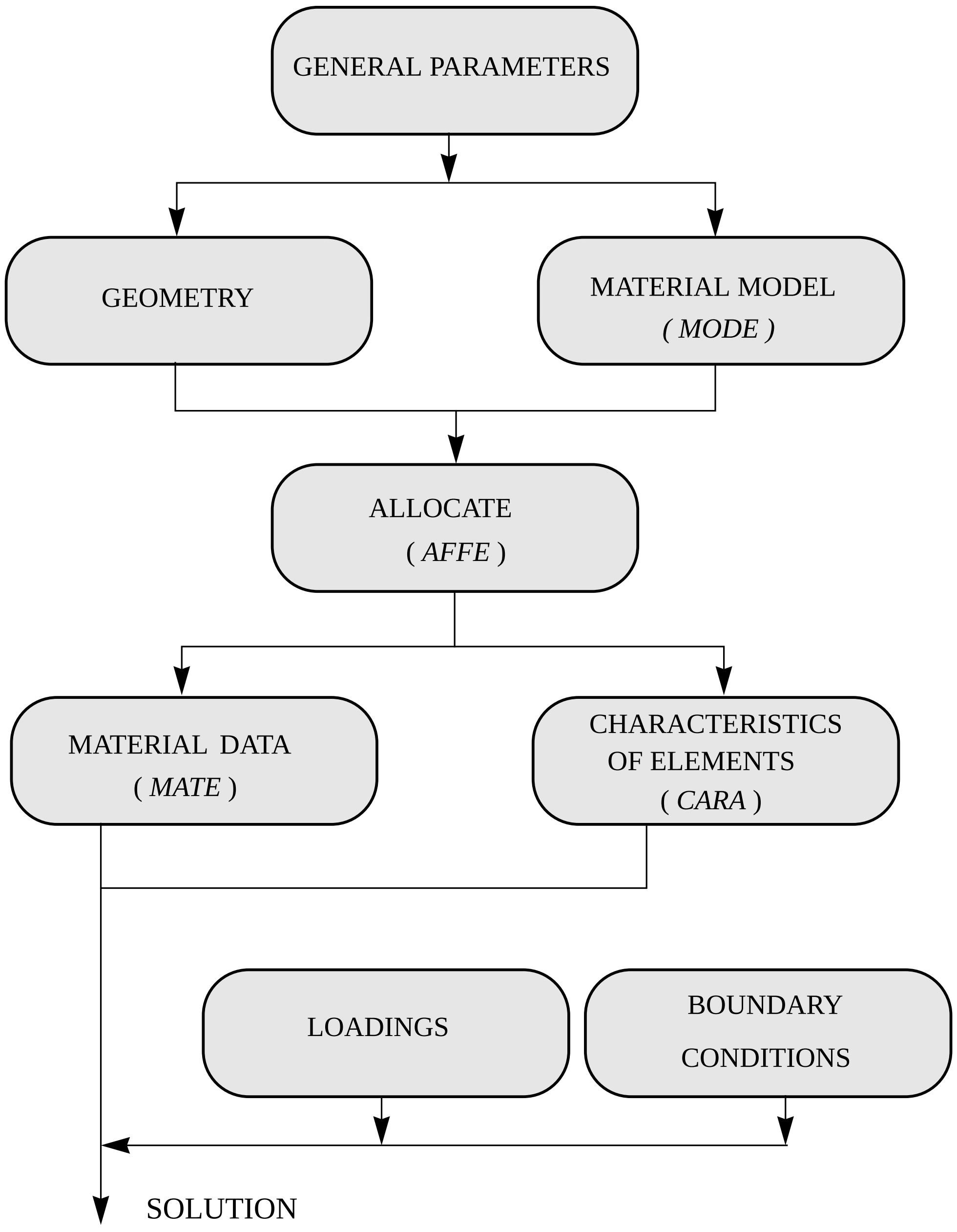
- all the data relating to geometry, material behavior and characterization of the finite element formulation grouped together in an AFFECTE or MMODEL type object;

- all the data relating to the boundary conditions grouped together in a CHPOINT type object as for the loadings, and a RIGIDITE type object as for the constaints.

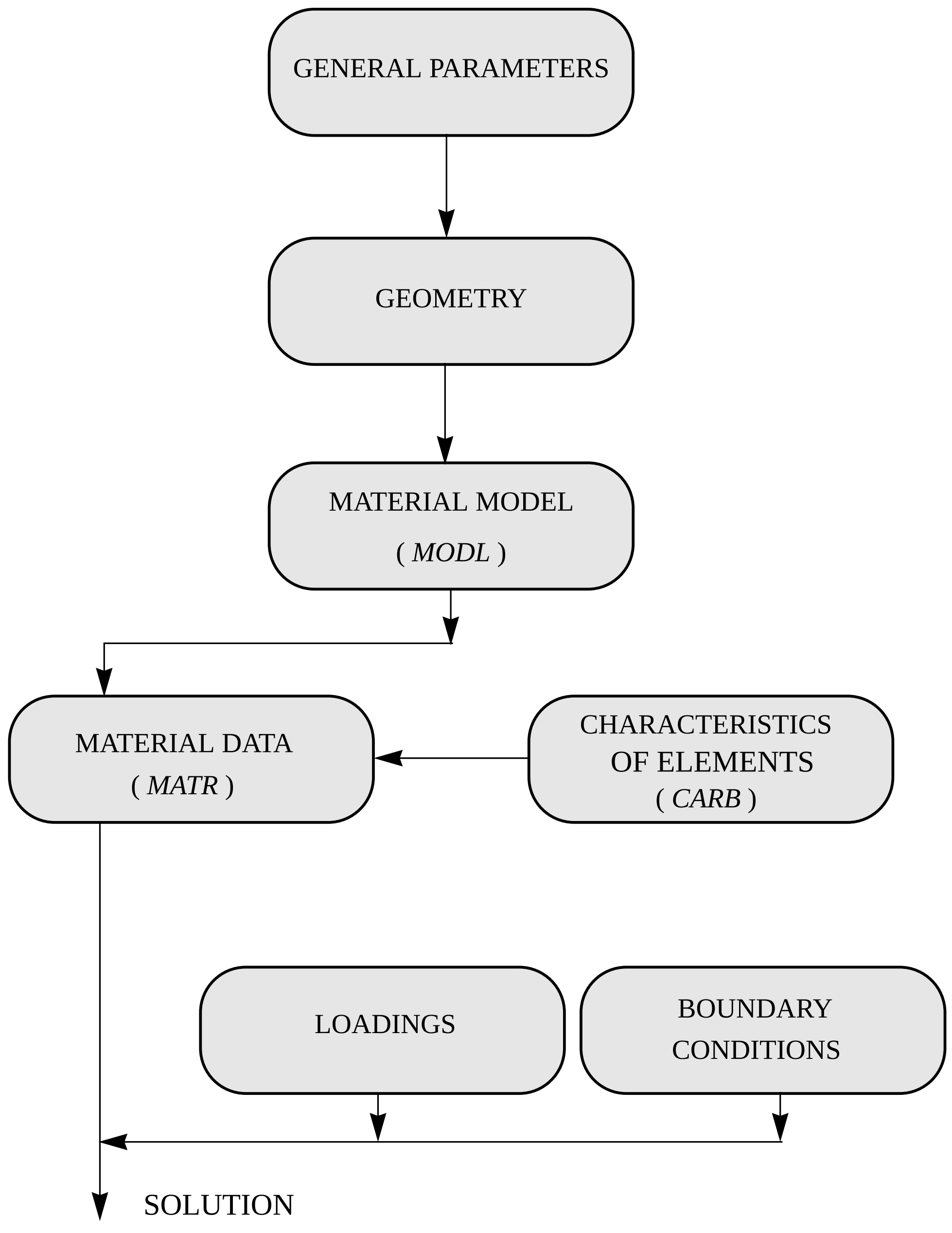
These data are organized rationally in the CASTEM2000 sense in the following synoptic table.

The two diagrams respectively correspond to the use of former and new fields by elements.

FORMER CHAMELEMS



<u>NEW CHAMELEMS</u>



The logic illustrated in the previous diagrams can be expressed in terms of operators as follows:

NEW CHAMELEMS

```
*General parameters

   OPTI DIME 3
   ELEM QUA8 ;

*Definition of the geometry

   P1 = 0. 0. 0. ;
   P2 = 1. 0. 0. ;
   L1 = DROI 2 P1 P2 ;
   S8 = L1 TRAN 2 ( 0. 1. 0. );

*Material model and F.E.

   MM = MODL S8 MECANIQUE ELASTIQUE COQ8 ;


*Material data

   CARMA = MATR MM YOUN 2E11 NU 0.3
                             RHO 7800;

*Other characteristics

   CAR1 = CARB MM EPAI 0.01;
   CARMA = CARMA ET CAR1 ;(*)

*Boundary conditions
```

```
    COND = BLOQ DEPL ROTA
                ( S8 COTE 2);

*Loading

    FOR1 = FORC ( 1E3 0. 0.)
                  (POIN 8 S8) ;

* Solution

    K = RIGI MM CARMA ;
    KTOT = K ET COND ;
    DEPL = RESO KTOT FOR1 ;
```

(*) It is also possible to give additional characteristics while defining the material data:

```
CARMA = MATR MM YOUN 2E11 NU 0.3 RHO 7800 EPAI 0.01;
```

As a result, the following is avoided:

```
CARMA = CARMA ET CAR1 ;
```

4.1. Definition of the geometrical model

In most of the preprocessing moduli of the computer codes by finite elements, there are two successive stages in the creation of the geometrical model:

- definition of the geometry using basic geometrical elements such as points, lines, surfaces and solids;
- generation of the mesh from the geometries and a series of parameters, types of elements and distribution of these elements on the sides for instance.

In CASTEM2000, on the contrary, a geometrical object whatever it may be only exists in discretized form. So the region of analysis is discretized into elementary geometrical elements as soon as the geometry has been defined; the objects defined in this way are stored in the

MAILLAGE type object.

The stage during which the geometrical model is generated corresponds to the creation of a series of MAILLAGE type objects which, once grouped together, compose the discretized region as a whole.

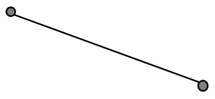
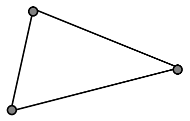
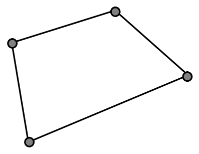
The MAILLAGE type objects are points, lines, surfaces, or solids; some operators enable their construction, others allow geometrical operations such as rotations, translations, intersections to be performed on them. It is also possible to call on other operators the functions of which are not limited to the geometrical area, and which can be used in other stages of the analysis (see chapter 3).

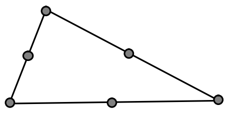
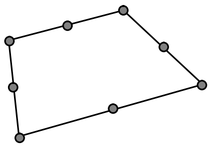
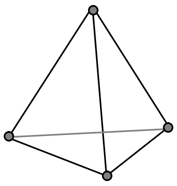
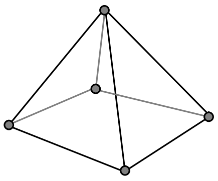
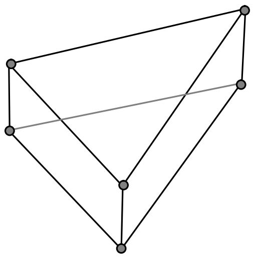
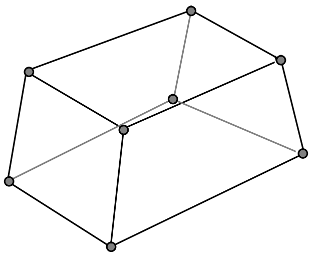
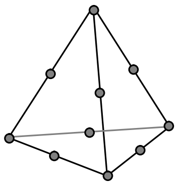
The elements defined while the geometry is being constructed constitute the geometrical support of the finite elements that will be used later on in the analysis. The characteristics of these elements will be specified in the next stage, while defining the calculation model. This means that a plane surface, for instance, is automatically generated and discretized into 3-node triangular elements apart from the fact that afterwards, these elements will be used with a plane or shell modelization.

CASTEM2000 has another important distinctive feature: the numbering relating to both the nodes and the elements is transparent.

The notion of object to which the name directly refers and the possible automatic creations actually allow the analyses to be developed using only the reference terminologies defined by the user.

Figure 1 shows the geometrical elements which can now be used automatically in the stage of creation. It also implies that F.E. formulations can be associated with each geometrical element.

Geometrical support	**Type**	**Finite elements**
SEG2		COQ2 (axisymmetrical) POUT, TUYA, BARR .. (beam, pipe, bar)
TRI3		TRI3, COQ3, DKT ...
QUA4		COQ4, QUA4 ....

Geometrical support	**Type**	**Finite elements**
TRI6		TRI6, COQ6 .....
QUA8		QUA8, COQ8
TET4		TET4
PYR5		PYR5
PRI6		PRI6
CUB8		CUB8
TE10		TE10

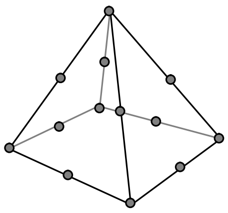
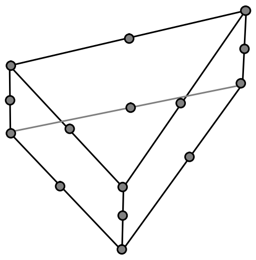
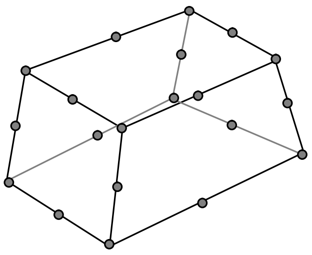
Geometrical support	**Type**	**Finite elements**
PY13		PY13
PR15		PR15
CU20		CU20

figure 1

In order that the user learn easily the incremental method used in CASTEM2000 for the creation of geometrical models, we have described below the process of creation of elementary objects (points, lines, surfaces, solids)

As for the process of manipulation of these operators by means of operators specific to the stage of modelization, report to the description of these operators (see following paragraphs). Chapter 3 describes the general operators liable to be also used in the stage of modelization.

4.1.1 Creation of points

A point is the object of the simplest mesh.

Once the dimensions of the problem have been defined by means of the following directive:

`OPTION DIME n` ; (see 4.6.1)

a point is constructed by the association of the following coordinates with its name:

`Pi = Xi Yi ;` (in 2D, n=2)

`Pi = Xi Yi Zi ;` (in 3D, n=3)

A real number “d” standing for density, i.e. for the dimensions of the elements converging on that point is also created;

the corresponding directive is then as follows:

`DENS d ;`(see 4.6.1)

If during the construction of the geometrical model, it proves necessary to modify the dimensions of the problem, a null coordinate will be added to the points already created or the third coordinate will be removed, depending on whether one moves from 2D to 3D, or from 3D to 2D.

The program numbers the points as they are created in ascending order. Once known, this number can be obtained by interactive query or by listing the corresponding object; the NOEU operator enables the user to attribute a name to the points, even to those created by automatic procedures (see creation of lines in 4.1.2).

As for the POIN operator, it can either give a name to any point defined by its number (like NOEU), or identify the points located at the intersection of a MAILLAGE type object and a given line or surface.

Given any MAILLAGE type object, the BARY operator makes it possible to determine the barycentre of that object, be it a line, surface, or volume, by attributing the name defined by the user to it.

4.1.2 Creation of lines

A line is always constructed from its two extreme points according to the rule enabling the computation of the coordinates of internal points.

Depending on the rule, it is therefore possible to generate different types of lines using various operators as shown in table A and Figure 2.

As soon as the lines have been created, they are automatically subdivided into a certain number of segments. This number depends on the density at the extreme points of the line: the length of the segments actually stands for a geometrical progression between the values of the densities at the ends.
It is also possible to directly specify the number of segments of a line: in this case, all the segments will be the same length.

The created lines can be composed of two-node (SEG2 elements) or three-node (SEG3 elements) segments depending on whether the following directive is used:

`OPTI ELEM SEG 2 ;` (see 4.6.1)

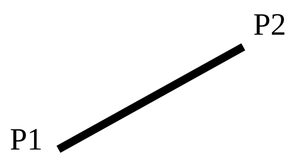
or

`OPTI ELEM SEG3 ;`

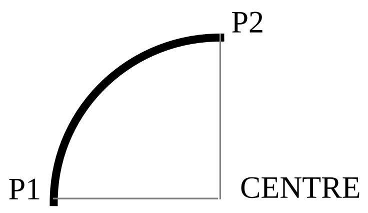
Type	**Definition**	**Examples**
DROIT	2 points	LIGNE = DROI P1 P2
CERCLE	3 points	ARC = CERC P1 CENTRE P2
CER3	3 points	ARC = CER3 P1 P2 P3
PARABOLE	3 points	ARC = PARA P1 PINT P2
CUBP	4 points	ARC = CUBP P1 P2 P3 P4
CUBT	2 points and 2 vectors	ARC = CUBT P1 V1 P2 V2
COURBE	n points	polynomial curve of order n-1
QUELCONQUE	n points	broken line passing by the n given points
INTERSECTION	2 points and 2 surfaces	ARC = P1 INTE S1 S2 P2

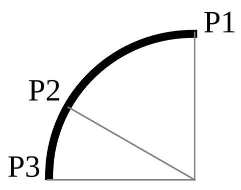
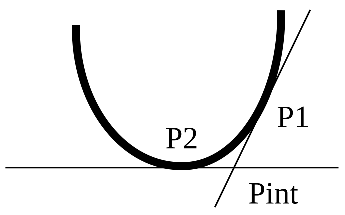
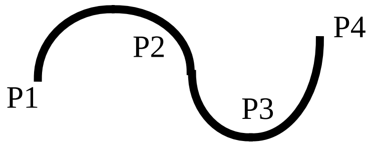
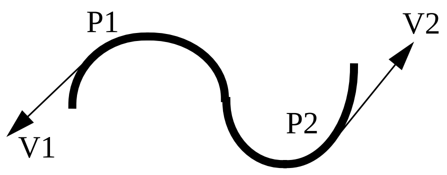
Table A

type	**definition**	**examples**
DROIT	2 points	`LIGNE=DROI P1 P2`

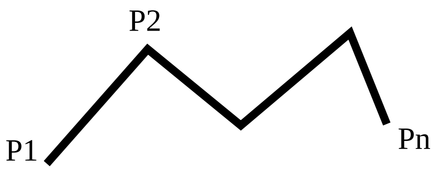


CERCLE	3 points	`ARC=CERC P1 CENTRE P2`



type	**definition**	**examples**
CER3	3 points	`ARC=CER3 P1 P2 P3`
		
PARABOLE	4 points	`ARC=PARA P1 PINT P2`
		
CUBP	4 points	`ARC=CUBP P1 P2 P3 P4`
		
CUBT	2 points + 2 vectors	`ARC=CUBT V1 P2 V2`
		

type	**definition**	**examples**
COURBE	n points	Polynomial curve of order (n-1)
QUELCONQUE	n points	`LIG1=QUEL SEG2 P1 ..PN`



INTERSECTION	2 points + 2 surfaces	`ARC=P1 INTE S1 S2 P2`

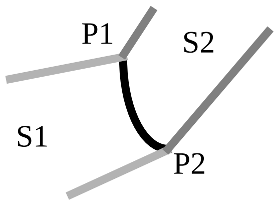


figure 2

As mentioned previously, the internal points of a created line are accessible only through the number that the program attributed to them, for instance with the following instructions:

```
OPTI DIME 2 ELEM SEG2 ;
     P1 = 0. 0. ;
     P2 = 3. 0. ;
 LIGNE = DROI 3 P1 P2 ;
```

A straight line composed of 3 segments of equal length is created. As a result, the NOEU operator makes it possible to give a name to the intermediate nodes 3 and 4:

```
N3 = NOEU 3 ;
N4 = NOEU 4 ;
```

4.1.3 Creation of surfaces

There are three different ways for creating a surface:

- from a certain number of lines which compose its perimeter on a fixed geometrical surface
- by the translation or the rotation of any type of line
- from its polynomial equation written in parametrical form

In the first case, the surface can stem from one of the following five geometrical elements: plane, sphere, cylinder, cone or torus.

The mesh which is automatically constructed on a surface can be composed of triangular or quadrangular elements, or both. However, if the surface is composed of quadrangular elements only, either the contour will have to be regular or the sides opposite this contour will have to be subdivided into an equal number of segments. The dimensions of the elements created on each surface are defined by the density values at the nodes of the contour.

The ELIM directive makes it possible to delete within a surface, or between two surfaces the nodes whose relative distance is smaller than a certain specified value (including double nodes); this may prove necessary when several regions of the mesh are generated separately then grouped together in the same object (to be avoided).

After ELIM, one can use the REGE operator which makes it possible to correct the topologies of the elements by deleting the sides which after ELIM are of null length. As a result, the elements of the model are regenerated, the TRI3 elements are turned into SEG2, the QUA4 into TRI3 and so on, as shown below:

TRI3	-->	SEG2
QUA4	-->	TRI3
TRI6	-->	SEG3
QUA8	-->	TRI6
CUB8	-->	PRI6
CU20	-->	PR15

4.1.1 Construction of volumes

In the same way as lines had been created from points, and surfaces from lines, volumes are defined from surfaces. The user can select between these two possibilities:

- generate the volume by the translation or the rotation of a given surface (VOLU operator);

- generate the volume from its external surface (PAVE).

The options offered by the VOLU operator also enable the constuction of a volume from two surfaces - top and bottom -, by means of rectilinear segments.

The mesh constructed by automatic operators can be composed of both prismatic elements with rectangular basis and tetrahedral elements. Each of these elements is available either in the linear displacement version, or in the quadratic displacement version by means of the following directive:

```
OPTI ELEM geometrical_element_type
```

4.2. Definition of the characteristics of the material

In CASTEM2000, the stage during which the characteristics of the materials are being defined corresponds to the creation of a field by element (MCHAML) type object. This field can be single for the whole area of analysis if the latter is composed of one type of material. If it is composed of several types of materials, the user will define as many fields by elements as there are regions of materials with different characteristics.

With former CHAMELEMS, the structure complete mathematical model is obtained as soon as the geometrical model is constructed, by associating the corresponding physical characteristics with it, or by defining the type of behavior and the material properties.

With new CHAMELEMS, the field of properties (material and geometrical) is constructed once the geometrical model, the material behavior, and the finite element are associated.

4.2.1 Linear elastic materials

4.2.1.1 Constant properties

Four operators (MODL, MODELE) and (MATR, MATER) are used to define linear elastic materials.

MODL and MODELE are used to define an isotropic or orthotropic behavior within the framework of linear elasticity.

As for MATR and MATER, they give the material properties such as Young’s modulus, Poisson’s ratio, the density, the thermal expansion coefficient, the directions of orthotropy etc.

Operators construct fields by elements with several components.

4.2.1.2 Properties varying with a parameter

Combining appropriate sequences of general operators with the (MODL, MODEL) and (MATR, MATER) operators described below makes it possible to define a material whose properties vary with time.

By way of an example, we have chosen the characteristic case of a linear material for which Young’s modulus linearly depends on temperature. It consists in composing, in an EVOLUTION type object, two definite progressions containing the temperature values T and the corresponding values of Young’s modulus in order to obtain the function E(T).

As soon as the connection between E and T is established, it is associated with the temperature scalar field by points defined from the analyzed region and constructed above.

This very field by points is then turned into a field by elements which will in turn be associated with that containing the other properties of the material.

The sequence of appropriate control is as follows:

NEW CHAMELEMS

```
* YOUNG’s modulus 2D model=F(T)

* T inversely proportional to the square distance
* from the origin

* construction of the geometrical model

     OPTI DIME 2 ELEM QUA4 ;
     P0 = 0. 0. ;
     P1 = 10. 0. ;
     COTE1 = D 10 P0 P1 ;
     GEO = COTE1 TRAN 10 ( 0. 10.) ;

* construction of the temperature CHPOINT

     DISTX = COOR 2 GEO ;
     DISTY = COOR 1 GEO ;
     DIST0 = ( DISTX * DISTX ) +
             ( DISTY * DISTY) ;
     TEMP = 1. / DIST0 ;
     TEMPE = NOMC YOUN (200 - TEMP) ;

* progression containing the temperature values

     PRGT =PROG 0. 200. ;

* progression containing the values of YOUNG’s modulus

     PRGY = PROG 2.E11 1.E11 ;

* function E(T)

     YT = EVOL MANU PRGT PRGY ;

* CHPOINT containing the values of YOUNG’s modulus

     CHPYT = TEMPE * YT ;

* definition of the behavior model and F.E.

     MM = MODL GEO MECANIQUE ELASTIQUE QUA4;

* transformation CHPOINT E(T) into CHAMELEM E(T)

     CHAMYT=CHAN ‘CHAM’ CHPYT GEO ;

* definition of the material properties

     PMAT = MATR MM YOUN CHAMYT NU 0.3 ALPH 1.E-6;
```

Besides, there are special operators for automatically applying complex-type boundary conditions (SYMT, ANTI ...).

For structural applications, the conditions of displacement and/or imposed rotation can be specified by referring to the three usually accepted directions or to any of the directions defined by the user.

4.3. Definition of boundary conditions

In CASTEM2000, the boundary conditions on the values of the unknown function are processed by the Lagrangian multipliers method.

In practise, the series of boundary conditions is defined as follows:

$$\underline{\mathbf{C}}\ \underline{u} = \underline{q} \qquad \underline{(1)}$$

in which C is a matrix of constant coefficients and q the vector of values imposed on the nodal displacements; in this case, the Lagrangian multipliers method consists in writing the system of linear equilibrium equations as follows:

$$\begin{aligned} \underline{\mathbf{K}}\ \underline{u} + \underline{\mathbf{C}}^{T}\ \underline{\lambda} &= \underline{f} \\ \underline{\mathbf{C}}\ \underline{u} &= \underline{q} \end{aligned} \qquad (2)$$

where vector $\underline{\lambda}$ contains unknown multipliers.

In order to have the resolution system (2), the user must therefore explicitely combine the stiffness matrix $\underline{\mathbf{K}}$ of the free system with the matrix $\underline{\mathbf{C}}$, whereas the vector $\underline{q}$ must be added to the vector of nodal equivalent loadings $\underline{f}$.

In accordance with (1), the definition of the boundary conditions given in CASTEM2000 includes the creation of a RIGIDITE type object corresponding to the vector $\underline{q}$.

Of course this vector equals zero when only the null values of the nodal unknowns $\underline{u}$ have to be imposed.

The user can generate as many stiffness objects and as many additional fields by points as there are boundary conditions to be analyzed.

In CASTEM2000, formula (1) enables the processing of boundary conditions referring to linkages between different portions of a same region whether of absolute or relative type.

The boundary conditions can be specified by referring to MAILLAGE type objects such as points, lines, surfaces and volumes, and by specifying the degrees of freedom concerned with the boundary conditions.

4.4. Definition of loading

4.4.1 Constant mechanical loadings

In CASTEM2000, the stage during which external loadings are being defined corresponds to the creation of a vectorial or scalar field by points, depending on the application. This field corresponds to the vector of the known right-hand sides used in the resolution of the system of equilibrium equations, without taking into account the boundary conditions described in chapter 4.3.

The user is free to generate as many fields by points as there are independent loading conditions to be considered in the analysis stage, either successively or together.

Properly selected operators enable a direct specification of concentrated loadings and/or regularly distributed surface loadings.
The mass and/or non regularly distributed loadings can easily be generated by means of selected sequences of general operators. A few specific cases will be detailed in the following pages of this manual.

4.4.1.1 Eigen weights

The generic loading vector stemming from the mass forces is expressed as follows:

(1)

$$\underline{f} = \int_V \underline{\boldsymbol{N}}^T \times \underline{b} \times dV$$

where V stands for the studied region, **N** the matrix of shape functions, and b the vector of mass force densities.

In the case of an eigen weight, we have:

$$b(x, y, z)=\rho g(x, y, z)$$

where ρ stands for the mass density, and g the acceleration vector.

If for convenience, the vector g is expressed in relation to its nodal values by way of the shape functions, formula (1) can be rewritten as follows:

$$\underline{f} = \rho \int_V \underline{\boldsymbol{N}}^T \times \underline{\boldsymbol{N}} \times dV \times g_n$$

where the vector g_n contains the nodal values of the g acceleration.

The calculation of the loading vector corresponding to an application of a gravitational loading in direction z can thus be performed in three stages :

- calculation of the mass matrix of the region

-

$$\underline{\underline{\boldsymbol{M}}} = \rho \times \int_V \underline{\boldsymbol{N}}^T \times \underline{\boldsymbol{N}} \times dV$$

- definition of a vectorial field by point CPA containing the nodal components of the acceleration vector g_n

- multiplication of the mass matrix M by the field CPA.

NEW CHAMELEMS

```
* model definition

  MM = MODL ....
  MA = MATR MM ......

* calculation of the stiffness matrix

  K= (RIGI MM MA) ET C.L

* calculation of the mass matrix

  M = MASS MM MA

* construction of the acceleration field by point

  CPA = MANU CHPO GEO 1 UZ -9.81;

* nodal equivalent forces

  POIDSPR = M*CPA;

* system solution [K] {DEPL} = {POIDSPR}

  DEPL = RESO K POIDSPR;
```

4.4.2 Thermal loadings

The generic vector for the thermal loading (temperature field imposed on a constrained structure) is expressed as follows:

$$\underline{f} = \int_V \underline{\boldsymbol{B}}^T \times \underline{\boldsymbol{D}} \times \underline{\alpha} \times \underline{N}^T \times \underline{T}_n \times dV$$

where:

- $\underline{\alpha}$ is the vector of thermal expansion coefficients

- $\underline{N}^T \underline{T}_n$ is the temperature punctual vector defined by interpolating nodal values $\underline{T}_n$

The loading vector corresponding to the application of a thermal loading can thus be calculated in three stages:

- definition of a scalar field by point CPT, containing the temperature nodal values;

- calculation of the field by elements containing the stresses equivalent to the thermal distribution defined by:

$$\underline{\sigma}= \underline{\mathbf{D}}\ \underline{\alpha}\ \underline{N}^T\ \underline{T}_N$$

- calculation of nodal equivalent forces:

$$\underline{f} = \int_V \underline{\boldsymbol{B}}^T \times \underline{\sigma} \times dV$$

It is advisable to input the following control sequence:

<u>NEW CHAMELEMS</u>

```
* definition of the field by point containing the temperature
* values (here the whole structure is at 100 degrees)
```

```
  CPT=MANU CHPO GEO 1 T 100;

* calculation of the stresses equivalent to the temperature
* field

  SIGT=THETA MMODEL MATERIAU CPT;


  FEN=BSIG MMODEL SIGT;


  DEPL=RESO K FEN;


  SIG=(SIGM MMODEL MATERIAU DEPL) - SIGT;
```

4.5. Characteristics of elements and selection of the formulation

The appropriate formulation must be chosen during the last stage of definition of the calculation model.

In other words, the user must select the type of finite elements and specify, if necessary, the geometrical characteristics which can be directly infered from the geometry (shell thickness, properties of the beams transverse sections...).

The operator used for selecting the formulation (geometry + material model + type of finite elements) creates an AFFECTE or MODL type object.

Additional characteristics of the elements are selected by means of the CARA or CARB operator (if the latter are not specified by MATR as for new chamelems). CARA and CARB generate a CHAMELEM or MCHAML type object.

5. Resolution of the discretized problem

By resolution of the discretized problem, we understand all the mathematical operations required for calculating the vector of the unknows in the system of discretized equations to which any formulation applies.

To reach this stage, it is required that one first calculates the matrices (stiffness, mass, conductivity...) obtained by an integration on the studied discretized region, the magnitudes specific to the type of problem to be solved (elementary stiffnesses, material density, conductivity...).

The problem can be solved using the operators or sequences of appropriate operators as soon as the matrices have been constructed.

5.1. Static linear elastic analysis

Solving a problem in the static area as for structures amounts to searching for the discretized displacement field, for a finite number of nodal points stemming from the application on the studied region of a set of boundary conditions.

As already mentioned, these boundary conditions can be external forces, temperature fields, initial deformation stress fields, imposed displacements fields, giving rise to the nodal equivalent loadings.

In fact, solving a problem amounts to solving a system of linear equations:

$$\underline{\mathbf{K}}\ \underline{u} = \underline{f}$$

where $\underline{\mathbf{K}}$, stiffness matrix, contains all the data relating to the geometrical characteristics (dimensions), the physical characteristics (material properties) and the constrained degrees of freedom of the structure; $\underline{f}$ stands for the nodal equivalent loadings and $\underline{u}$ the set of unknown nodal displacements.

5.1.1 Substructures

The substructure method is very efficient for analyzing complex structures by subdividing them into smaller components which can therefore be handled more easily.

Each part or substructure is modeled independently of the others and its degrees of freedom are reduced by static condensing. The static condensing procedure enables the removing of a few unknowns of the system arising from equilibrium equations, by replacing them in the remaining equations. As a result, the loadings and equivalent stiffnesses are obtained in relation to the selected nodal points, and both the gathering and the resolution of these values allow the initial problem to be solved.

The degrees of freedom of each substructure according to which the matrices are reduced are usually those located on the contour in order to ensure the continuation with the adjacent substructures.

In the static area, the solution obtained by means of this technique is either correct or equals that which would be obtained if the structure had been studied as a whole. Nevertheless, when this technique is used advisedly, the matrices of each substructure are usually far smaller than those of the complete structure and they demand shorter periods of time for being solved and less memory space for each stage of resolution.

An analysis by substructure consists of three basic distinct stages:

1 . Reduction of substructure matrices

The degrees of freedom of each substructure are reduced so as to generate a stiffness and some loadings equivalent to the contour.

If $\underline{u}_e j$ stands for the external degrees of freedom, and $\underline{u}_i j$ the internal degrees of freedom of the jth substructure, the system of linear equilibrium equations will be divided $\underline{K}^j\ \underline{u}^j = \underline{f}^j$ and then:

$$\underline{\mathbf{K}}_{ee} j\ \underline{u}_e j + \underline{\mathbf{K}}_{ei} j\ \underline{u}_i j = \underline{f}_e j$$
$$\underline{\mathbf{K}}_{ie} j\ \underline{u}_e j + \underline{\mathbf{K}}_{ii} j\ \underline{u}_i j = \underline{f}_i j$$

where $\underline{u}^j=\{\underline{u}_e j^T\ \underline{u}_i j^T\}^T$, $\underline{f}^j=\{\underline{f}_e j^T\ \underline{f}_i j^T\}^T$

Besides all the connections with the adjacent substructures, $\underline{u}_e j$ may contain the degrees of freedom of other nodes.

The stresses on the internal degrees of freedom must be clearly imposed in this stage.

It is at that point that the static condensing is performed. The second system is solved in relation to $\underline{u}_i$; the equivalent loadings and stiffnesses can be obtained by replacing the result outcoming in the first system:

$$\underline{f}_s j = \underline{f}_e j - \underline{\mathbf{K}}_{ei} j\ \underline{\mathbf{K}}_{ii}\ j\text{-}1\ \underline{f}_i j$$
$$\underline{\mathbf{K}}_s j = \underline{\mathbf{K}}_{ee} j - \underline{\mathbf{K}}_{ei} j\ \underline{\mathbf{K}}_{ii} j\text{-}1\ \underline{\mathbf{K}}_i ej$$

2 . Solution obtained if the degrees of freedom are retained

The matrices obtained in stage 1 are gathered together to generate the resolution system of equations:

$$\underline{\mathbf{K}}_s\ \underline{u}_s = \underline{f}_s$$

At this stage, other boundary conditions can be imposed on the degrees of freedom which are stored and the resulting equations can be solved in relation to $\underline{u}_s$.

3 . Retreival of internal degrees of freedom

So the displacements $\underline{u}_e j$ of the external nodes of the j^{ith} substructure have been deduced from the displacement of the external nodes of the complete structure $\underline{u}_s$.

One then returns to the displacements of the internal nodes $\underline{u}_i j$ by means of the second equation of the system (1):

$$\underline{u}_i j = \underline{\mathbf{K}}_{ii} j\text{-}1\ \underline{f}_i j - \underline{\mathbf{K}}_{ii} j\ \underline{\mathbf{K}}_{ie} j\text{-}1\ \underline{u}_e j$$

so as to be able to proceed with a postprocessing.

The SUPER operator of CASTEM2000 can perform by itself all the operations for condensing and retreiving the internal degrees of freedom, for both the stiffness matrix and the vector of nodal loadings. For further information, report to the handbook. For the time being, we would suggest you to study a simple example of analysis by substructures.

The structure studied and the substructures from which it is made are shown in the following figure:

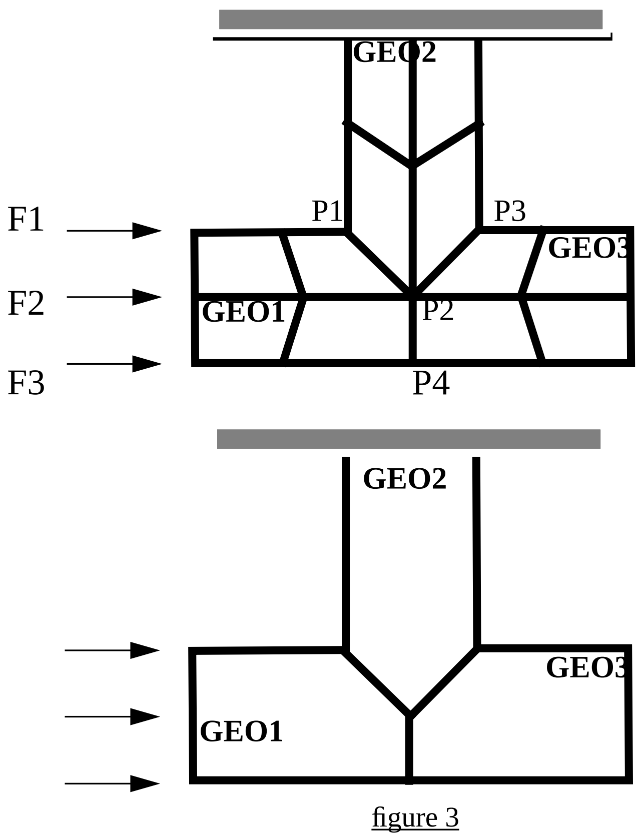


figure 3

The substructure matrices are reduced with respect to the sole degrees of freedom of the interface nodes: line I1 is composed of the nodes P1, P2 and P4 by GEO2 and line I3 is composed of the nodes P3, P2 and P4 by GEO3.

5.2. Modal analysis

Locating a structure eigen frequencies and modes amounts to solving the following homogeneous system:

$$(-\omega^2 \underline{\mathbf{M}} + \omega \underline{\mathbf{C}} + \underline{\mathbf{K}})\, \underline{u} = \underline{0}$$

where **M** stands for the mass matrix, **C** the damping matrix, **K** the stiffness matrix, the eigen pulsation ($\omega=2\pi f$) and $\underline{u}$, the vector accounting for the extent of nodal displacements.

Since CASTEM2000 does not take into account the damping values, the problem relative to eigen vibrations amounts to:

$$(-\lambda\, \underline{\mathbf{M}} + \underline{\mathbf{K}})\, \underline{u} = \underline{0}$$

where $\lambda=\omega^2$.

This system assumes two solutions different from zero for $\underline{u}$, only for certain values of λ which precisely correspond to the structure eigen pulsations.

An eigen vector $\underline{u}$ of the same eigen mode corresponds to each λ.

If **K** is real, symmetrical and non singular, the number of eigenvalues different from zero meeting condition (2) equals **M** order. In a partly or totally free structure (non constrained), the stiffness matrix is singular and there are as many null eigenvalues as there are possible stiffness motions.

6. Processing of results

It usually proves vital to process the results of an analysis carried out with CASTEM2000; they are contained in the CHPOINT or SOLUTION type object and are obtained by solving the equations corresponding to the phenomenon studied; this processing should enable the calculation of derivative magnitudes that will then be processed more easily; it should also allow the results to be displayed in order to be interpreted as rightly as possible.

Hence the two categories of operators of the program one of which is intended for postprocessing whereas the other is destined for graphic display.

In principle, the postprocessing operators are used for calculating magnitudes to be displayed in graphs. These magnitudes are always defined in appropriate objects provided on input to the TRAC operator. This operator serves as a driver for the graphic display of both the geometry during its creation and the results in the form of deformed shapes, symbols for vectorial magnitudes (arrows), line contours, or color bands.

Besides the potentialities of the TRAC operator, it is possible to get graphs in the X-Y plane and three-dimensional diagrams.

It should be remembered that all the data available in CASTEM2000 objects can be displayed on screen or stored in an appropriate file to be printed later on. This can be done by means of the general operator LIST which once judiciously combined with the parameters of the OPTI operator enables the transmission of requested data on the selected unit.

7. Procedures

CASTEM2000 can be used by anybody following the rules of exploitation of the program that meet as best as possible the requirements of the problem to be solved. In fact, combining different operators between them makes it possible to define resolution procedures which can be complex and the preparation of which demands basic knowledge of mechanical computation, but has been made easier by the programming language - both very simple and concise - and by the special operators allowing loops and instructions to be executed.

The precoded procedures prepared according to the method described below are particularly useful for repetitive calculations which can be performed directly once the sequence of basic controls has been developed and checked out. This enables the user (even if he is not yet familiar with the program) to solve complex problems.

Moreover, the user should keep in mind that a procedure does not necessarily cover the whole resolution process for a calculation problem.
In fact, the same data architecture can be used for carrying out a series of analyses and for the definition and prior macro-coding of general interest. Each macro control thus defined plays the same part as an operator but it develops a complex function. Several standard elementary operators of CASTEM2000 participate in its execution which is transparent to the user.

In conclusion, it can be said that defining the precoded procedures as offered by CASTEM2000 is particularly well suited when integrated in the problem to be solved; this is true of any application of the program.

7.1. Definition of a procedure

7.1.1 During the execution

Setting up any resolution procedure or control macro amounts to inserting all the controls for activating and processing the operators requested between an initial control (DEBP) and a final control (FINP), as shown below:

```
DEBP name_procedure objects*’type’ objects/’type’;
.
.
.
requested operations
.
.
.
FINP;
```

A procedure or control macro can be defined at the start of the execution (data sets) by merely inserting the DEBP control followed by the name of the procedure and the list of available objects.

Moreover, any object must be followed by its type (format *’type’) when it is required for the procedure to progress smoothly or (format /’type’) when it is optional and corresponds to a special application.

The objects required for running the procedure can also be supplied directly during this very procedure, in interactive mode, by means of the OBTE and MESS operators.

At the end of the procedure, just after the FINP control, the user should specify, when necessary, the list of objects generated during the execution which must be retreived for continuing the execution.

Let us assume the CILRET procedure allowing the cartesian coordinates of a point P1 to be calculated from its cylindrical coordinates; it can have an open or closed definition by means of controls such as:

```
DEBP CILRET A*’FLOTTANT ’ B*’FLOTTANT’ C/’FLOTTANT’;
.           (floating)
.
.
.
FINP D;
```

where A, B and C refer to the cylindrical coordinates R, σ and Z, and D, the internal name of the point to which the rectangular coordinates are attributed.

It should be noted that the object corresponding to the coordinate Z has been defined as /'FLOTTANT' because the procedure can be used in both 2D and 3D so it may or may not be regarded as a declared argument.

Later on, this procedure will be found again in the course of the execution, by a simple insertion, in the same way as for an operator.

Example :

```
P1=CILRET RAYON TETA Z;
```

7.1.2 By means of an external file

Instead of being defined directly in the execution stage, the procedures or controls macro can be defined in advance and be memorized on the appropriate file (GIBI.PROC) for a later use after the processing stage.

In this case, the controls for the procedure definition should include another control for the identification, such as:

```
*$$$$ name_procedure
```

In the aforementioned case of the CILRET procedure, the memorization should therefore be performed as follows:

```
*$$$$ CILRET
DEBP CILRET A*'FLOTTANT' B*'FLOTTANT' C/'FLOTTANT';
.
.
.
FINP D;
```

Whenever he classifies a new procedure in the proper corresponding file, the user should not forget to run a series of operations enabling him to use it directly.

The basic operation consists in turning the formatted procedure file into a non formatted file by means of the secondary program creproc, so as to be accessible to CASTEM2000.

IF **gibi.procedure** is the name of the formatted file containing all the procedures, one will have to proceed as follows for creating a “direct access” file:

- assign **gibi.procedure** to the logical unit 20
- GIBI.PROC to the logical unit 10
- run the creproc program.

7.2. Examples of procedures

7.2.1 Procedure reseved for static linear elastic analysis

In accordance with the schematization of an approach by finite elements and the logic adopted in CASTEM2000, it is possible to carry out a static linear elastic analysis in several stages:

- (1) interactive definition of a MAILLAGE (GEO) type object or retreival of this object on a stack file;

- (2) definition of the elastic linear behavior model of the material in a MMODEL (MOD1) type object containing also the geometric type data and data on the finite element formulation;

- (3) definition of the material characteristics and of possible additional characteristics of the elements, MCHAML (MAT1) type object;

- (4) definition of possible additional characteristics of the elements and of the material characteristics, CARB (CAR1) type object if they have not already been specified in MAT1;

- (5) definition of kinematic type boundary conditions by the construction of a RIGIDITE (COND) type object;

- (6) definition of conditions of loading and/or displacement imposed by the construction of a CHPOINT (FORCES) type object;

- (7) calculation of the stiffness matrix of the free structure (STIF);

- (8) assembly of the stiffnesses stemming from the elements and the stress conditions in a global RIGIDITE (KTOT) type object;

- (9) resolution of the linear system [KTOT] {DEPL} = {FORCES};

- (10) calculation of stresses (SIGMA) from the displacement vector (DEPL);

- (11) backup of the main objects (GEO, DEPL, SIGMA, MOD1, MAT1) required for the execution of a later graphical postprocessing;

After having presented the sequential execution, let us now assume the hypothesis of a recurrent application characterized by:

- (a) the use of geometrical models requiring the use of shell type elements with 3 and 4 nodes which are of the same thickness e=0.001.

- (b) the constant use of some steel with the following characteristics: E=2.1 1011, n=0.3 and ρ=7850.

- (c) the sole use of mechanic type loadings corresponding to concentrated forces and moments and/or to uniform pressures.

In this case, it is very useful to define an appropriate procedure with a view to recurrent applications; it already contains all the precoded selections and all the parameters of analysis that are unlikely to vary.

This procedure can be called CALINE (CAlcul LINeaire Elastique i.e. Elastic LINear Calculation) and can be defined as follows:

```
*$$$$ CALINE

DEBP CALINE GEO*’MAILLAGE’ COND*’RIGIDITE’ FORCES*’CHPOINT’

(2)MOD1=MODL GEO MECANIQUE ELASTIQUE COQ3 CO4;

(3)MAT1=MATR MOD1 YOUN 2.1E11 NU 0.3 RHO 7850 (EPAI 0.001);

(4)(CAR1=CARB MOD1 EPAI 0.001 ; MAT1=MAT1 ET CAR1;)

(7)STIF=RIGI MOD1 MAT1;

(8)KTOT=STIF ET COND;

(9)DEPL=RESO KTOT FORCES;

(10)SIGMA=SIGM MOD1 MAT1 DEPL;

(11)OPTI SAUV ‘FORMAT’ ‘essai.sortgibi’;
```

```
(11) SAUV ‘FORMAT’ GEO DEPL SIGMA MOD1 MAT1;

FINP ;
```

As shown by the numbers attributed to the instructions, the procedure decribed above is capable of running all the stages of static linear elastic analysis except for the geometry (1), and the boundary conditions (5) and (6). Stage (4) is optional and is required only when the additional characteristics are not mentioned in stage (3).

As a result, the user can perform a calculation by merely defining what is needed at points (1), (3) and (4) before calling on the CALINE procedure by means of the following instruction:

CALINE name_mesh name_boundarycond name_forces;

7.2.2 Procedure reserved for modal analysis

CASTEM2000 makes it possible to carry out the analysis relating to the extraction of the eigen frequencies and modes of a structure in several stages (See Modal analysis section 5.2):

- (1) interactive definition of a MAILLAGE (GEO) type object or retreival of this object on a stack file;

- (2) definition of the elastic linear behavior model of the material in a MMODEL (MOD1) type object containing also geometric type data and data on the finite element formulation ;

- (3) definition of the characteristics of the material and of possible additional characteristics of the elements, MCHAML (MAT1) type object;

- (4) definition of possible additional characteristics of the elements and of the characteristics of the material, CARB (CAR1) type object if they have not already been specified in MAT1;

- (5) definition of kinematic type boundary conditions by the construction a RIGIDITE (COND) type object;

- (6) calculation of the stiffness matrix of the free structure (STIF);

- (7) assembly of the stiffnesses stemming from the elements and the boundary conditions in a global RIGIDITE (KTOT) type object;

- (8) calculation of the structure mass matrix (MTOT);
- (9) calculation of the first eigen modes and frequencies of the structure (AUTO);
- (10) backup of the main objects (GEO ...) required for a further graphic postprocessing;

Besides the aforementioned sequence of operations, it is possible (in the case of a recurring situation characterized by the points (a) and (b) of the previous section in which solely the first 5 eigen frequencies smaller than 200 Hz must be determined) to define an appropriate procedure which already contains all the precoded selections, the parameters of analysis being unlikely to vary.

This procedure can be constructed as follows:

```
*$$$$ VALPRO

DEBP VALPRO GEO*’MAILLAGE’ COND*’RIGIDITE’

(2)MOD1=MODL GEO MECANIQUE ELASTIQUE COQ3 COQ4;

(3)MAT1=MATR MOD1 YOUN 2.1E11 NU 0.3 RHO 7850 (EPAI 0.001);

(4)(CAR1=CARB MOD1 EPAI 0.001 ; MAT1=MAT1 ET CAR1;)

(6)STIF=RIGI MOD1 MAT1;

(7)KTOT=STIF ET COND;

(8)MTOT=MASSE MOD1 MAT1;

(9)AUTO=VIBR INTE 0. 200. BASSE 5 KTOT MTOT;

(10)OPTI SAUV ‘test2.sortgibi’;

(10)SAUV GEO AUTO MOD1 MAT1;

FINP ;
```

As shown by the numbers attributed to the instructions, the procedure decribed above, is capable of running all the stages of the modal analysis except for the geometry (1) and the boundary conditions (5).

As a result, the user can perform a calculation by merely defining what is needed at the points (1) and (5) before calling on the VALPRO procedure by means of the following command:

```
VALPRO name_mesh name_boundarycond;
```

7.2.3 Precoded procedures

In this version of CASTEM2000, there are several precoded procedures. A complete list and a brief description of the procedures are given in annex C.

ANNEXES

ANNEX A

This section gives the different types of elements available in CASTEM2000 as well as the corresponding geometrical support and the nature of the possible calculations with the following conventions:

cont plane	:	plane stresses
defo plane	:	plane strains
axis	:	axisymmetrical
four	:	Fourier's analysis
trid	:	three-dimensional

ELEMENT	GEOMETRICAL SUPPORT	NATURE OF CALCULATION
MASSIVE ELEMENTS		
TRI3	TRI3	cont plane,defo plane,axis,four
TRI6	TRI6	"
QUA4	QUA4	"
QUA8	QUA8	"
CUB8	CUB8	trid
CU20	CU20	"
TET4	TET4	"
TE10	TE10	"
PRI6	PRI6	"
PR15	PR15	"
PYR5	PYR5	"
PY13	PY13	"
THIN SHELL ELEMENTS		
COQ3	TRI3	trid
DKT	TRI3	trid
COQ2	SEG2	cont plane,def plane,axis,four
THICK SHELL ELEMENTS		
COQ8	QUA8	trid
COQ6	TRI6	"
COQ4	QUA4	"
DST*	TRI3	"
BEAMS AND PIPES		
POUT	SEG2	trid

ELEMENT	GEOMETRICAL SUPPORT	NATURE OF CALCULATION
TUYA	SEG2	“
BARS		
BARR	SEG2	cont plane,def plane,axis,trid
ELEMENTS OF RUPTURE MECHANICS		
LISP	RAC2	trid
LISM	RAC2	“
TUFI	SEG2	“
LIQUID ELEMENTS FOR ACOUSTICS		
LTR3	TRI3	cont plane,def plane
LQUA4	QUA4	“
LCU8	CUB8	trid
LPR6	PRI6	“
LPY5	PYR5	“
LTE4	TET4	“
LIQUID-MASSIVE TRANSITION ELEMENTS		
RAC2	RAC2	cont plane,def plane,axis,four
LIA3	LIA3	trid
LIA4	LIA4	“
LIQUID-SHELL TRANSITION ELEMENTS		
RACO	RAC2	cont plane,def plane,axis,four
LICO	LIA3	trid
FREE SURFACE ELEMENTS		
LSU2	SEG2	cont plane,def plane,axis,four
LSU3	TRI3	trid
LSU4	QUA4	trid
POROUS ELEMENTS		
TRIP	TRI6	cont plane,def plane,axis
QUAP	QUA8	“
CUBP	CU20	trid
TETP	TE10	“
PRIP	PR15	“
HOMOGENEIZED ELEMENTS		
TRIH	TRI3	cont plane,def plane,axis

ANNEX B

This section briefly describes all the operators and directives available in CASTEM2000.(92 Clients' Version).

The names in italics (*AFFE*) refer to the operators that are to disappear.

Bold names (**BIOT**) refer to both the new and the modified operators.

name	description
/	division
*****	multiplication
+	addition
<EG	less or equal
-	substraction
******	exponentiation
>EG	greater or equal
<	less
>	greater
ABS	absolute value
ACT3	convergence acceleration
ACTI	convergence acceleration
AFCO	color allocated to a mesh
AFFE	finite element allocated to a mesh
AFFI	construction of a mesh by affinity
AMOR	constructs a diagonal damping matrix
ANTI	imposes antisymmetrical boundary conditions on the displacement and/or rotation d.o.f
APPU	constructs a stiffness associated with linear supports (springs) applied to d.o.f
ARETE	construction of a mesh representing the edges of another mesh (3D only).
ARGU	reading of arguments within a procedure
ATG	arctangent
BARY	barycentre of a geometry
BASE	creation of a BASE MODALE type object
BIOT	constructs an induction field (3D only)

name	description
BLOQ	boundary conditions with respect to the principal axes
BRUI	creation of white noise
BSIGM	calculation of equivalent forces
CABLE	construction of the stiffness of a cable
CALP	calculation of a stress field (shells and beams)
CAPA	creates a thermal capacity matrix
CAPI	calculates a Piola-Kirchoff stress field from a Cauchy field
CARACTERISTIQUE ***(CARA)***	elements geometrical characteristics (former chamelems)
CARACTERISTIQUE **(CARB)**	elements geometrical characteristics (new chamelems)
CER3	construction of an arc of a circle
CERC	construction of an arc of a circle
CHAM	turns a CHPOINT into a CHAMELEM
CHAN	- turns the type of element of a mesh into another type - turns an MCHAML or a CHAMELEM into a CHPOINT - turns a CHAMELEM into an MCHAML - modifies the subtype of an MCHAML - creates a CHAMELEM from an MCHAML - creates a MMODEL from an AFFECTE - turns a CHPOINT into an MCHAML
CHAR	construction of a loading
CHOC	construction of an impact link
CHOL	decomposition of a matrix according to the CROUT method
CHPO	creation of a field by point
CHSP	modifies the type of a spectrum
CLST	creation of a structure constraint
CMOY	calculation of a mean impact
COLI	weighted linear combination of fields
COMB	linear combination of fields by points
COMM	comments
COMP	construction of a line between two points

name	description
COMT	calculation of the number of impacts in an impact recording
CONC	joins two objects
COND	construction of a conductivity matrix
CONF	merges two points
CONG	construction of a hollow curvature
CONT	construction of the contour of an object
CONV	imposes a forced convection
COOR	finds again the coordinates of a point, mesh, CHPO, MCHAML (or CHAMELEM)
COPI	duplication of an object
COS	cosine of an object
COTE	construction of the side of an object
COUL	color attributed to an object
COUR	construction of a polynomial curve
COUT	construction of a surface by connecting two lines
CREC	creation of a constant CHAMELEM
CRIT	calculation of the criterion of a plastic model
CUBP	construction of an arc of a cubic
CUBT	construction of an arc of a cubic
DALL	construction of a surface within a contour
DEBI	calculation of the forces stemming from an imposed flow
DEBP	beginning of a procedure
DEDU	construction of a mesh from two other meshes (TRI3 and QUA4 only)
DEFO	construction of a DEFORME type object
DENS	density of a mesh
DEPB	construction of an ATTACHE type object (imposed displacements)
DEPI	imposes non null displacements imposes the right-hand side of a relation
DEPL	displacement of a POINT or MAILLAGE type object
DESS	plot of EVOLUTION type objects
DETR	destruction of an object
DEVE	construction of an ATTACHE type object (weir)

name	**description**
DEVO	calculation of the solution of a system of matrix equations
DFOU	calculation of a CHPO or MCHAML (or CHAMALEM) for a given angle (Fourier's analysis)
DIAG	number of negative eigenvalues of a RIGIDITE type object
DIFF	symmetrical difference between two MAILLAGE type objects
DIME	dimension of an object
DIMN	dimension of the kernel of the stiffness matrix
DROI	construction of a straight line
DSPR	construction of the power spectrum density curve of a signal
DTAN	calculation of a tangent matrix
DYNE	calculation of a dynamic response by explicit algorithm
EGA	comparison between two objects
ELAS	calculation of strains from stresses calculation of stresses from strains
ELEM	extraction of the elements of a MAILLAGE type object
ELFE	test of the different algorithms on beams or plates
ELIM	removal of the nodes located between two MAILLAGE type objects
ELST	construction of an ELEMSTRU type object
ENER	calculation of the tensorial product of a stress field and a strain field
ENLE	removes objects from a list of objects
ENSE	creation of a SOLUTION type object containing all the modes of a structure
ENTI	conversion of a floating into an integer
ENVE	creation of the envelope of a volume creation of the envelope spectrum of a series of spectra
EPSI	calculation of the strain field

name	description
ERREUR	processing of errors calculation of an error field
ET	fusion of two objects of same type
EVOL	creation of an evolution type object
EXCE	research for the minimum of a function
EXCI	determination of active constraints in case of unilateral constraints
EXCO	extraction of the component from an MCHAML (or CHAMELEM) or CHPO type object
EXIS	test to check whether an object exists
EXP	exponential
EXTR	extraction of an object value or component
FACE	finds again the side of a volumic mesh
FDT	creation of a function (EVOLUTION type object) from a time step
FILT	calculation of filters
FIN	program or block stop
FINP	end of procedure
FINSI	end of a block SI-SINON
FLOT	conversion of an integer into a floating
FLUX	imposes a flow on a part of the contour of a structure
FOFI	calculation of a nodal force field
FONC	calculation of Bessel or Fresnel functions
FORCE	creation of a force field
FORME	manipulation of CONFIGURATION type objects (discretization fields)
GENE	construction of a surface generated by a generatrix
GRAD	calculation of the gradient of a displacement field
GRAF	calculation of the flexural gradients in the thin shells
GREEN	calculation of Green functions associated with beams
HOMO	construction of a mesh by homothety
HOOK	calculation of Hooke’s matrices

name	description
HOTA	calculation of Hooke’s tangent matrices in plasticity
IFRE	calculation of Fresnel integrals
INCL	extraction of an object located within a contour
INDE	gives all the indices of a table
INDI	supplies information about the quality of a mesh (planearity criterion only)
INFO	gives an operator instructions
INSE	insertion of an object into a list of objects
INTE	construction of a line, intersection of two surfaces
INTG	integration of a field component on a region
INVA	calculation of the three invariants of a tensor
INVE	inversion of the direction of a line
IPOL	linear interpolation
ITER	interruption of a block running
JACO	calculation of a jacobian absolute value
JONC	creation of an ATTACHE type object (connection between substructures)
KP	calculation of the pressure matrix
KSIG	calculation of the initial stress matrix
KTAN	calculation of the tangent stiffness matrix in elastoplasticity
LAPL	construction of Laplace transfom
LECT	creation of a list of integers
LIAI	creation of connections between substructures
LIRE	reading of a mesh on a logical file
LIST	information about objects
LOG	logarithm
LUMP	construction of a diagonal matrix
MANU	creation of objects (MAILLAGE, CHPO, SOLUTION, RIGIDITE, MCHAML, CHAMELEM)
MAPP	construction of a Poincarre-type chart
MASQ	construction of a field composed of 0 and 1 from a field by elements or a field by points.
MASS	construction of the mass matrix

name	description
MATE	gives the properties of a material (CHAMELEM)
MATR	gives the properties of a material (MCHAML)
MAX1	normalizes an object with respect to its maximum component
MAXI	finds again the maximum of a field by points, field by elements or LISTMOTS
MENA	releases memory space
MESS	message display
MINI	finds again the minimum of a field by points, field by elements or LISTMOTS
MODE	definition of the material type (CHAMELEM)
MODI	mesh interactive modification on screen
MODL	definition of the material type (MCHAML)
MOIN	calculation of the difference between two objects; translation of an object
MOME	creation of a punctual moment
MOT	attribution of an alias to a key word
MOTA	calculation of the tangent modulus
MOTS	creation of a list of MOT type objects
MULT	comparison between two integers
NBEL	gives the number of elements of a MAILLAGE type object
NBNO	gives the number of nodes of a MAILLAGE type object
NEG	comparison between two objects
NNOR	normalizes a SOLUTION type object
NOEUD	identification of the node of a mesh by its number or name
NOMC	modification of the name of a component of a field by point
NON	logical negation
NORM	calculation of the norm of a vector
NOTI	printing of GIBI or CASTEM2000 manual
OBTE	interactive acquisition of objects
OPTI	definition of the calculation general options
ORDO	sorting out of a list of objects

name	description
ORIE	orientation in the same direction of all the sides of a mesh
ORTH	orthogonalization of an object with respect to other objects
OSCI	calculation of an oscillator response
OU	or logical
OUBL	clears the name of an object from the memory
PARA	construction of an arc of a parabola
PAVE	creation of volumic elements inside a parallelepipedic surface
PERM	construction of a permeability matrix for elements in porous medium
PICA	conversion of a Piola-Kirschoff stress field into a Cauchy stress field
PJBA	calculation of the force projection onto a modal basis
PLAC	gives the size of the available memory space
PLAS	calculation of a field of plastically acceptable stresses
PLUS	translation of an object
PMIX	vectorial product
POIN	extracts one or several points from a geometry extracts the maximum or minimum point(s) of one or several components from a field
PRCH	conversion of a field by points into a field by elements by an interpolation based on the form functions of the finite element formulation
PRES	calculation of the field of nodal forces equivalent to a distributed pressure
PRHC	conversion of a field by elements into a field by points
PRIN	calculation of the principal stresses
PROG	creation of a list of real numbers
PROI	calculation of the projection of an object onto a new geometry
PROJ	projection of an object according to a given direction
PSCA	scalar product of two vectors or two fields

name	**description**
PSMO	calculation of the contribution of the modes which were not taken into account in a modal basis
PVEC	vectorial product
QUEL	construction of a broken line
QUIT	block running interrupted
QULX	extraction of the Lagrangian multipliers of a CHPO type object
RACC	transition between two objects
RCHO	calculation of impact forces and projection onto the modes contained in the modal basis
REAC	calculation of the reactions at constraint points
RECO	recombination of the modes and static solutions
REDU	reduction of a field by points or field by elements to a given support
REGE	regeneration of a mesh containing degenerated elements
REGL	construction of a ruled surface
RELA	creation of linear relations between degrees of freedom
REMP	replaces an object in a list of objects
REPE	specifies how many times a loop is repeated
RESO	resolution of the linear system **K**u=f
RESP	restitution of the results calculated in a procedure
REST	restoration back to memory of the objects saved on a file
RESU	calculation of the resultant of a CHPO type force field
RIGI	construction of the stiffness matrix
RIMP	conversion of a complex SOLUTION type object
ROTA	contruction of a surface by the rotation of a line or a surface
RTENS	reorientation of a field by elements for massive and shell elements in a new and direct orthonormal basis
SAUF	modification of a list of real numbers or integers
SAUT	skip of line(s) or page(s)

name	**description**
SAUV	backup of one or several objects on a file
SEIS	construction of a loading from a seism modal basis
SI	logical test
SIGM	calculation of a stress field from a displacement field
SIGN	gives the sign of a real number or integer
SIGS	calculation of stresses from a SOLUTION type object
SIN	sine of objects
SINO	alternate condition
SOLS	construction of static solutions
SOMM	calculation of the integral of a SOLUTION type object
SORT	writing of a MAILLAGE type object on a file
SOUR	imposes a volumic source of heat
SPO	calculation of oscillator spectra
STRU	creation of a STRUCTURE type object
SUBS	program temporary interruption and return to the CMS system (IBM VM only)
SUIT	creation of a list of CHPO objects
SUPE	creation of one super-element
SURF	construction of a surface inside a contour
SYME	construction of a symmetrical object
SYMT	imposes symmetrical boundary conditions
SYNT	calculation of the modes of a structure from those of the substructures
TABLE	creation of a table type object
TAGR	calculation of the transposed matrix of a gradient matrix
TASS	reorders the numbering of a MAILLAGE type object
TEMP	gives the time since the last occurence
TEXT	construction of a text from objects
TFR	construction of a signal fast Fourier transform
TFRI	construction of a signal inverse Fourier transform

name	description
THETA	calculation of the stresses associated with a temperature field
TIRE	extraction of an object stemming from a solution type object extraction of a CHPO type object stemming from a CHARGEMENT type object
TITR	definition of a title
TOTE	calculation of the sum of the intervals on which one of the abscissas of a function exceeds a limit
TOUR	construction of an object stemming from the rotation of another object
TRAC	graphic output for MAILLAGE, CHPO, MCHAML (CHAMELEM) type objects
TRAN	construction of a surface generated by the translation of a line
TRESCA	calculation of Tresca equivalent stress
TYPE	gives the object type
VALE	finds again the values of the general calculation operations
VALP	calculation of the eigenvalues of a tridiagonal matrix
VARI	construction of a variable field
VECT	creation of a vector type object
VERS	checks the direction of the elements of a mesh
VIBR	calculation of the eigen modes and frequencies of an object
VMIS	calculates a stress equivalent to a stress field (Von-Mises stress in the case of 2D and 3D massives)
VOLU	construction of a volume by translation, rotation, or automatically from a closed surface
WORK	calculation of the trace of the contracted tensorial product of a stress field with a gradient field
XTMX	calculation of the symmetrical bilinear form $^{t}X.M.X$
XTX	calculation of the scalar product $^{t}X.X$
XTY	calculation of the scalar product $^{t}Y.X$

name	**description**
YTMX	calculation of the symmetrical bilinear form ${}^{t}Y.M.X$
ZERO	creation of a field by element the components of which are all null

ANNEX C

Index of the procedures in alphabetical order

Bold names (**ACIER**) refer to both the new and the modified procedures.

name	description
ACIER	allows the material properties of the 316L steel to be defined in the system S.I
ACIER1	procedure called on by ACIER if former chamelems
ACIER2	procedure called on by ACIER if new chamelems
ACTI3	evaluates the displacement incremental field allowing the problem relating to the restriction of the application tangent to the 3D subspace defined by input fields to be solved
AFFICHE	makes it possible to display the deformed shape of a structure
ANIME	allows an animation to be constructed from a strain field
ANNOIMP	allows the mesh of an imperfect ring to be generated
BOA	interactive mesh of lines of pipes
CALCULE1	procedure called on by CALCULER if former chamelems
CALCULE2	procedure called on by CALCULER if new chamelems
CALCULER	allows an assisted input of the data required for performing a 2D calculation in linear elasticity
CH_THETA	determines a THETA type field which is called on by the G_THETA procedure
CRITLOC	in postprocessing, enables the user to apply a damage criterion for rupture analysis
CRITLOC1	procedure called on by CRITLOC if former chamelems
CRITLOC2	procedure called on by CRITLOC if new chamelems

name	**description**
DFNL	procedure called on by NONLIN used in the calculation of plastic correcting forces
DYNAMIC	allows a step by step dynamic calculation to be performed
DYNAMOD2	procedure called on by DYNAMODE
DYNAMOD3	procedure called on by DYNAMODE
DYNAMODE	allows the dynamic response of a structure to be calculated
FACTORIE	allows the factorial of an integer to be calculated
FLAMBAG1	procedure called on by FLAMBAGE if former chamelems
FLAMBAG2	procedure called on by FLAMBAGE if new chamelems
FLAMBAGE	allows buckling calculations to be performed
G_THETA	allows the energy restitution rate to be calculated by the G-θ method
G_THETA1	procedure called on by G_THETA if former chamelems
G_THETA2	procedure called on by G_THETA if new chamelems
INCREME	procedure used by NONLIN; it allows a solution increment to be calculated for a loading increment in non linear
INCREME2	procedure called on by INCREME
JEU	allows the right hand side corresponding to a play between two solids to be calculated
LIREFLOT	in interactive, enables the user to read a real number between two boundaries
MONTAGNE	enables the display in 3D of the component of a field by points
NEWMARK	enables the step by step dynamic calculation of an incremental solution by Newmark centered algorithm
NONLIN	allows an incremental non linear calculation to be performed
NONLIN1	procedure called on by NONLIN if former chamelems
NONLIN2	procedure called on by NONLIN if new chamelems

name	**description**
PARKS	allows the energy restitution rate to be calculated by the crack virtual expansion method
PECHE	makes it possible to retreive the results of a calculation performed using NONLIN, for a given time
POINTCYL	allows a point to be defined by its cylindrical coordinates
POINTSPH	allows a point to be defined by its spherical coordinates
POLYNO	makes it possible to calculate a polynomial
PROPAG	reserved for the cracked piping element, it enables the user to determine the global moment-rotation behavior law of the element including the propagation
RESEAU	procedure called on by the TRACTUFI procedure
RESO_ASY	procedure called on by the RESO operator
SIGNCORR	procedure called on by SIGNSYNT
SIGNDERI	adds a straight line to a signal (EVOLUTION type object)
SIGNENVE	procedure called on by SIGNSYNT
SIGNSYNT	allows synthetic signals to be created by the recombination of random phase sinusoids
SISSI	enables an interactive input of the data required for a calculation with SISSI2
SISSI2	enables the calculation of the maximum response of a structure with seismic excitation
THERMIC	allows thermal problems to be solved, whether permanent or transient, linear or not
TRAC3D	allows the results of an axisymmetrical analysis to be displayed in 3D
TRACTUFI	makes it possible to determine the global behavior law of the cracked piping elements
TRADUIRE	allows a TABLE type object to be created from a SOLUTION type object (in modal analysis)
TRANSFER	allows the transfert function of a structure to be calculated (response to a localized force or to an overall acceleration)

name	description
TRANSIT0	procedure called on by the THERMIC procedure
TRANSIT1	procedure called on by the THERMIC procedure
TRANSIT2	procedure called on by the THERMIC procedure
TRANSIT3	procedure called on by the THERMIC procedure
UNILATER	cannot be called on by the user it is used for calculations with unilateral supports
VITEUNIL	procedure called on by NONLIN and NEWMARK in order to correct the velocities in case of unilateral supports
WEYBUL	makes it possible to calculate the probability to have an object ruptured by weybul law

2 nd PART

TRAINING MANUAL

1. INTRODUCTION

CASTEM2000 is a program with a powerful structure which offers innumerable possibilities to the user.

The goal of this section is to explain the notions of operators, objects and the way they are articulated.

This guide which is composed of a series of examples grouped together in “lessons” ranged from the less to the most difficult is intended for beginners. The user will be able to imagine by himself more and more powerful combinations of operators.

It is strongly advised that the user provide himself with the manual of operators before going and settling down in front of his computer, and that he enter the instructions presented in the lessons.

We suggest that he read no more than about ten lessons at once.

The beginners’ most common errors are listed at the end of this part; this will prevent the beginners from falling into the usual traps.

2. BASIC NOTIONS

2.1 Lesson 0 : GENERAL INTRODUCTION - NOTIONS OF OBJECT AND OPERATOR

Solving a problem by means of a computer program consists in following several stages such as descretizing a region (mesh), defining a few properties (material, boundary conditions, etc.), solving systems, examining the results...

As a general rule, each stage corresponds to one or several processes that acquire data, edit them, and create new ones when necessary.

So performing a calculation amounts to selecting elementary processes to be used, and to supplying them with the requested data.

In CASTEM2000, the processes are called **OPERATORS** and the sets of data are called **OBJECTS**.

- Objects are named by the user, which enables him to find and use them.

- Objects have been assigned a type, which enable the OPERATORS to process them.

- Objects take a part of the memory space allocated to the calculation.

The GIBIANE language developed from both operators and objects enables the user to specify his problem.

2.2 Lesson 1 : HOW TO ENTER CASTEM2000 PROGRAM

By way of introduction to CASTEM2000, the beginner should refer to the REFERENCE MANUAL, chapters DEBU, EXEM, GIBI, INTK, MECA, MEC1, MEC20.

For running CASTEM2000, at least two directives are needed:

- first, the **OPTION** directive enables the user to declare the program main parameters such as the space DIMENSION, the type(s) of ELEMENT used, the type of calculation...

Example :

```
*Declaration of parameters
    OPTION DIME 3 ELEM QUA4 PLAN CONT;
```

- second, the **FIN** directive enables the user to normally end the program running.

Between those two directives, it is possible to use any operator or directive. The user should keep in mind that an operator creates one or several objects whereas a directive does not.

An operator takes the following form:

OB1= OPERATEUR OB2 OB3;

OB1 is the object resulting from the OPERATEUR operator work

OB2, OB3 are the arguments objects, the number of arguments may be arbitrary.

In order to call on an operator, only the first four letters of its name are necessary.

Example :

```
    MAT1=MATR MO YOUN 2E11 NU 0.3;
```

A directive takes the following form:

DIRECTIVE OB4 OB5 ;

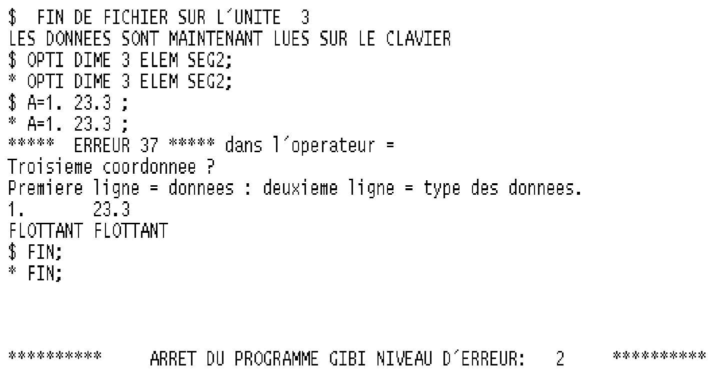
OB4 and OB5 are the argument objects, the number of arguments may be arbitrary.

Example:

```
TRAC OEIL1 GEO1;
```

If the objects supplied are not compatible with the operator or directive, an error message will be displayed, warning the user that he did not manage to get the result he expected; there will be also an indication about the kind of error.

Example:



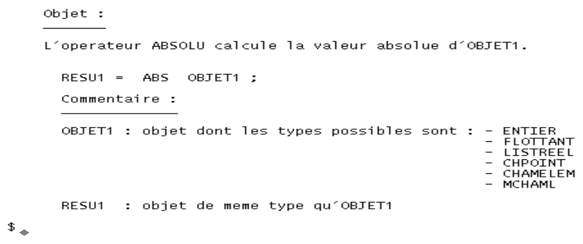
```
$  FIN DE FICHIER SUR L´UNITE  3
LES DONNEES SONT MAINTENANT LUES SUR LE CLAVIER
$ OPTI DIME 3 ELEM SEG2;
* OPTI DIME 3 ELEM SEG2;
$ A=1. 23.3 ;
* A=1. 23.3 ;
*****  ERREUR 37 ***** dans l´operateur =
Troisieme coordonnee ?
Premiere ligne = donnees : deuxieme ligne = type des donnees.
1.       23.3
FLOTTANT FLOTTANT
$ FIN;
* FIN;


**********     ARRET DU PROGRAMME GIBI NIVEAU D´ERREUR:   2     **********
```

In interactive mode, if the user does not understand the syntax of an operator, directive or procedure, he can get their instructions from the “in line help” by executing the following instruction:

INFO ABCD ;

where ABCD are the first 4 letters of the name of the requested operator (if it has at least four letters).

Example:



```
$  FIN DE FICHIER SUR L´UNITE  3
LES DONNEES SONT MAINTENANT LUES SUR LE CLAVIER
$ INFO ABS;
* INFO ABS;
                                            DATE     90/11/05
    Operateur ABS
    -------------                           Voir aussi : SIGN

    Objet :
    _______

    L´operateur ABSOLU calcule la valeur absolue d´OBJET1.

      RESU1 =  ABS  OBJET1 ;

      Commentaire :
      _____________

      OBJET1 : objet dont les types possibles sont : - ENTIER
                                                     - FLOTTANT
                                                     - LISTREEL
                                                     - CHPOINT
                                                     - CHAMELEM
                                                     - MCHAML

      RESU1  : objet de meme type qu´OBJET1

$
```

2.3. Lesson 2 : A FEW ELEMENTARY OBJECTS AND OPERATORS

a) ENTIER type objects:

They can be created with the sign = as follows:

Example:

```
I1=5 ;
I2= 7 ;
```

it is then possible to perform elementary arithmetic operations on these integers such as +, - * and / :

Example:

```
I3=I1 + I2;
I4=I1 * I2 ;
I5 =I1 / I2 ;
```

It is possible to know the result of these operations by listing the outcoming objects with the LIST directive

Example:

```
LIST I5 ;
```

b) FLOTTANT type objects:

They are created in the same way as the previous objects, apart from the fact that they must contain a decimal point or be written with powers:

Example:

`F1=1.5;` or `F1=15E-1;`

```
F2=2. ;
F3=F1 + F2 ;
LIST F3;
```

c) LOGIQUE type objects:

These objects can be created as follows:

Example:

```
BOL1 = VRAI ;
BOL2 = FAUX;
```

(the program recognizes the “words” VRAI (true) and FAUX (false)).

These objects can also be created with the comparison operators EGA, >EG, <EG, <, >.

The following instructions generate a logical object with a FAUX (false) value

Example:

```
I1=1;
I2=3 ;
BL1= I1 EGA I2;
LIST BL1;
```

The LOGIQUE, SI, SINON, FINSI type objects are used to control the execution of a block.

Example:

```
SI BOL1 ;
X=X+1 ;
SINON;
X=X-1;
FINSI;
```

d) LISTENTI or LISTREEL type objects

The user can create a collection of integers with the LECT operator, and a collection of real numbers with the PROG operator

Example:

```
X=3.4 ; K=30;
P1=PROG 1.2 2.3 X;
L1=LECT 20 K 40 50;
P2=PROG 12. 13.;
L2=LECT 60 70;
```

then, they can be joined by means of the ET operator.

```
P3=P1 ET P2;
L3=L1 ET L2;
```

This joining operator is general: it applies to most objects.

P3 will contain the floatings:

1.2 2.3 3.4 4.5 12. 13.

L3 the integers:

20 30 40 50 60 70

Remarks:

- An operator creates at least one object, and the name of the result is defined by the user.

- A directive modifies an existing object or produces an output on a logical unit (screen, printer, disk ...).

- An operator may sometimes generate several objects. The COOR operator, for instance, calculates the coordinates of a point (in two dimensions, 2 FLOTTANT type objects will be created, in three dimensions, 3 FLOTTANT type objects).

Example:

```
OPTI DIME 2;
C1=0. 1.;
F1 F2=COOR C1;

OPTI DIME 3;
C2=0. 0. 1.;
F1 F2 F3=COOR C2;
```

2.4 Lesson 3 : NOTION of NAMED object

a) Objects arising from an operator are named by the user

b) Some resulting objects may not be named.

In a chain calculation, there is no point naming intermediate results.

For instance, there are two ways to calculate 5x (2 + 3):

```
I=2+3;
J=5*I;
or
J=5*(2+3);
```

In the second case, the user performs his calculation in one instruction, but he will not be able to use this intermediate result 2+3 for other operators. For this reason, the program automatically attributed a name to the intermediate result which is a priori not accessible to the user.

c) Some data are automatically generated even before CASTEM2000 first instruction to be executed. They are the control parameters values created by the OPTION directive.

The most important are :

DIME : stands for the dimension of the space used for the mesh and calculation operators: 1, 2 or 3.

MODE stands for the calculation mode:

-2	: plane stresses
-1	: plane strains
0	: axisymmetrical
1	: Fourier series analysis
2	: three-dimensional

ECHO equals 1 or 0 depending on whether the last instruction echo is done or not.

DONN number of the logical unit on which the program reads the data:

5	: keyboard
3	: default number attributed to the data file

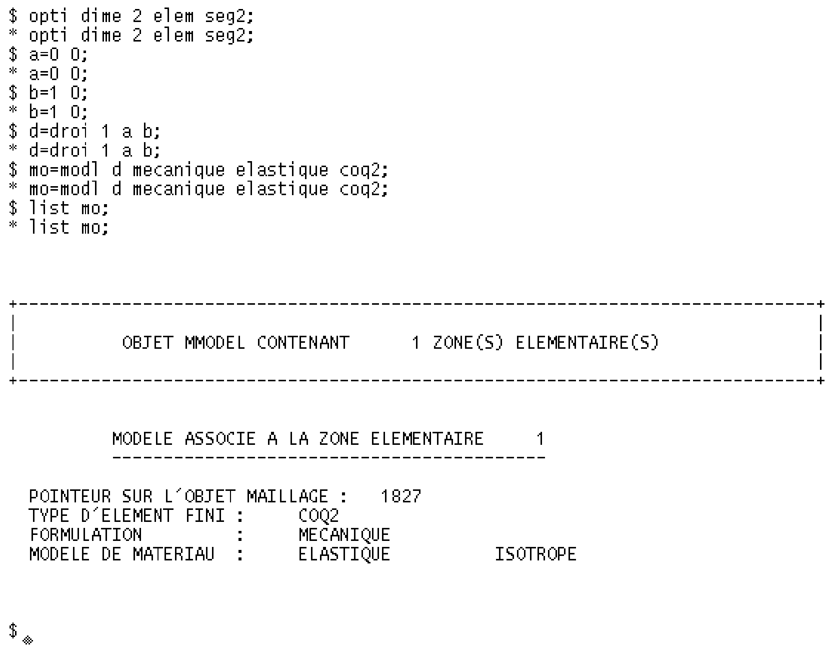
DENS stands for the current density (value used in meshing operations for specifying the reference length of a element).

2.5 Lesson 4 : TYPES OF OBJECTS

The various objects used in CASTEM2000 can store several kinds of data (integers or floatings, words, meshes, fields, etc.)

During the execution of CASTEM2000, the user can read, by means of the LIST directive, the objects type.

Example:



```
$ opti dime 2 elem seg2;
* opti dime 2 elem seg2;
$ a=0 0;
* a=0 0;
$ b=1 0;
* b=1 0;
$ d=droi 1 a b;
* d=droi 1 a b;
$ mo=modl d mecanique elastique coq2;
* mo=modl d mecanique elastique coq2;
$ list mo;
* list mo;


+----------------------------------------------------------------------------+
|                                                                            |
|          OBJET MMODEL CONTENANT      1 ZONE(S) ELEMENTAIRE(S)               |
|                                                                            |
+----------------------------------------------------------------------------+

          MODELE ASSOCIE A LA ZONE ELEMENTAIRE     1
          -----------------------------------------

  POINTEUR SUR L'OBJET MAILLAGE :   1827
  TYPE D'ELEMENT FINI :     COQ2
  FORMULATION         :     MECANIQUE
  MODELE DE MATERIAU  :     ELASTIQUE          ISOTROPE


$
```

The list of the different types of existing objects is given in chapter 3.1 of the user's manual.

Among other things, these different types of objects enable an operator to:

- check whether the objects supplied do represent the requested information.
- have a non positional syntax when all the argument objects of an operator have a different type.

3 MESH

3.1 Lesson 5 : POINT type objects

A point can be created in the following way:

Example:

```
OPTI DIME 2;
X=SIN 22.5;
P1=X 0.28;
```

(No operator is required with this object, the sign “=” is enough).

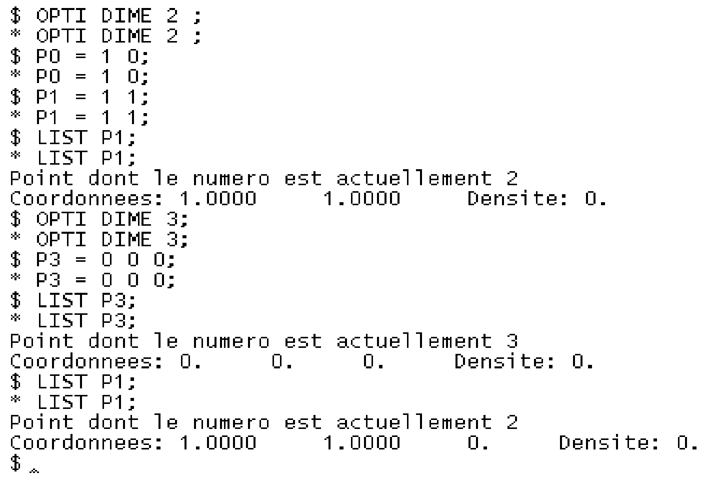
The space dimension must be specified with the OPTION directive before specifying any point.

If the dimension has been modified during the meshing process, a third null coordinate will be added to the existing points, or a coordinate will be removed depending on whether one moves from 2D to 3D or from 3D to 2D.

When a POINT type object is listed, an additional quantity comes up at the coordinates: it is the density, quantity which checks the average size of the sides of the elements that are connected to this point during automatic meshing processes. (By default, the density is null)

When a POINT type object is listed, its number which is exclusively used by the program comes up. This number can change using the SORT, TASS, and SAUV directives.

Example:



```
$ OPTI DIME 2 ;
* OPTI DIME 2 ;
$ P0 = 1 0;
* P0 = 1 0;
$ P1 = 1 1;
* P1 = 1 1;
$ LIST P1;
* LIST P1;
Point dont le numero est actuellement 2
Coordonnees: 1.0000     1.0000     Densite: 0.
$ OPTI DIME 3;
* OPTI DIME 3;
$ P3 = 0 0 0;
* P3 = 0 0 0;
$ LIST P3;
* LIST P3;
Point dont le numero est actuellement 3
Coordonnees: 0.     0.     0.     Densite: 0.
$ LIST P1;
* LIST P1;
Point dont le numero est actuellement 2
Coordonnees: 1.0000     1.0000     0.     Densite: 0.
$ _
```

The same type of POINT object is used for representing a point or a vector.

The PLUS operator (not to be mistaken with +) illustrates this statement :

Example:

```
C1 = 0. 0. ;
V3 = 2. 2. ;
C2 = C1 PLUS V3;
```

The same is true of the TRANS operator which uses a POINT type object standing for a vector.

Example:

```
V3 = 10. 10. ;
LI1 = C1 D 2 C2;
LI2=TRANS LI1 V3;
```

The user can get the number of points contained in an object with the NBNO operator any time:

Example:

```
NN1 = NBNO LI2;
```

3.2 Lesson 6 : CREATION OF LINES

The MAILLAGE type objects stand for line, surface or volume elements.
The simplest way to create them is to use the MANUEL operator followed by the key word referring to the type of element to be created.

Example:

```
QQ1 = MANU SEG2 C1 C2;
```

QQ1 is a 2-node segment connecting the points C1 and C2.

Of course, this method does not fit when the user wishes to create complex meshes; in this case, he will have to resort to automatic meshing operators. As for lines, the DROIT and CERC operators make it possible to build segments of straight line and arcs of circles.

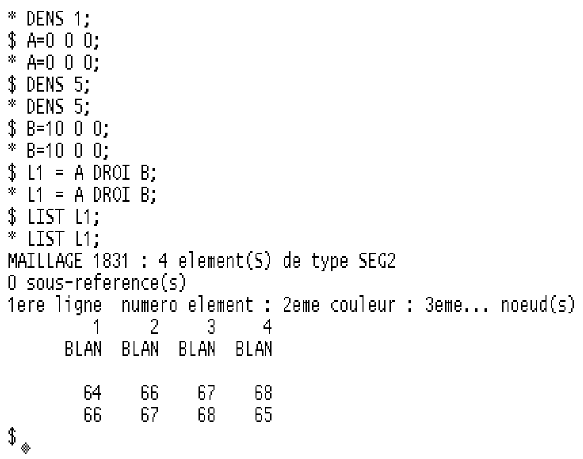
Example:

```
LI1 = C1 DROIT 3 C2;
CI1 = C1 CERC 4 C3 C2;
```

LI1 will be a straight line composed of 3 segments ranged between the points C1 and C2.
CI1 will be an arc of a circle composed of 4 segments, of centre C3 ranged between the points C1 and C2.

In this example, we have explicitely specified the number of segments for the creation of a line. This number can be checked by the densities attributed to the nodes of both origin and end C1 and C2, in relation to the current density.

Example:



```
* DENS 1;
$ A=0 0 0;
* A=0 0 0;
$ DENS 5;
* DENS 5;
$ B=10 0 0;
* B=10 0 0;
$ L1 = A DROI B;
* L1 = A DROI B;
$ LIST L1;
* LIST L1;
MAILLAGE 1831 : 4 element(S) de type SEG2
0 sous-reference(s)
1ere ligne  numero element : 2eme couleur : 3eme... noeud(s)
         1     2     3     4
      BLAN  BLAN  BLAN  BLAN

        64    66    67    68
        66    67    68    65
$
```

The DROIT and CERCLE operators will create 2-node lines (SEG2 elements) or 3-node lines (SEG3 elements) depending on whether the OPTION directive specified linear or quadratic elements.

This directive will also be employed to check the types of elements used in the generation of surfaces or volumes.

Remarks:

- The names of the DROIT and CERCLE operators can respectively be shortened in **D** and **C**.

- The DROIT and CERCLE operators create a certain number of points for building the segments.

These points will have no name and will be accessible to the user, at first, only through their internal numbers.

Example:

```
OPTI ELEM SEG2;
C1 = 0. 0. ;
C2= 1. 0. ;
LI1 = C1 DROIT 3 C2;
```

Two intermediate points with no name are created between C1 and C2. The user will be able to name them with the POINT operator:

```
N1 = POINT 3 LI1;
N2= POINT 4 LI1;
```

and list the coordinates (according to the x-axis for instance) of these points with the COOR operator.

```
LIST ( COOR 1 N1);
LIST (COOR 1 N2 );
```

The successive results will be the values .33 and .66, the x-coordinates of N1 and N2.

3.3 Lesson 7 : CREATION OF SURFACES OR VOLUMES

We have created lines from points; likewise we can create surfaces from lines, and volumes from surfaces.

These automatic meshing processes can be performed with the following operators:

DALLER, REGLE, ROTA, SURF, TRANS and VOLUME.

The size of the elements created within the contours is limited by the size of the elements of the contour.

Example:

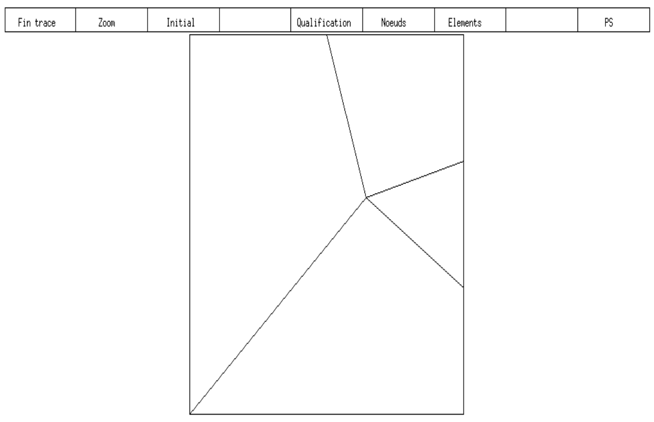
```
OPTI ELEM QUA4;
C1 = 0. 0. ;
C2 = 1. 0. ;
C3 = 1. 1. ;
C4 = 0. 1. ;
LI1 = C1 D 1 C2 D 3 C3 D 2 C4 D 1;
SU1 = LI1 SURF PLAN;
```

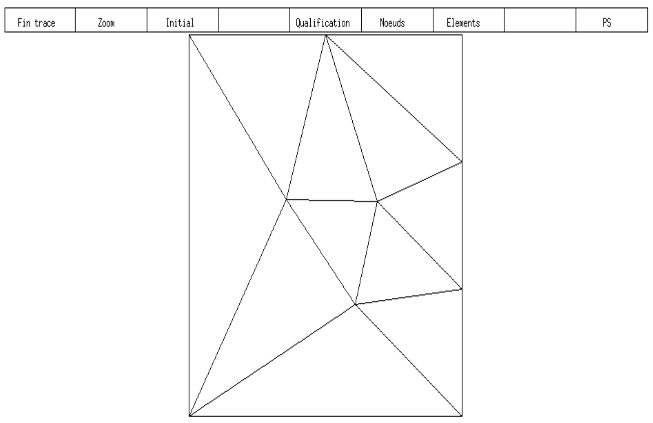
As a result, the surface SU1 will be meshed with 4-node quadrangles and 3-node triangles, and the line LI1 will be meshed with 2-node elements.

In fact, it is not possible to mesh any surface with only quadrangles and conform to an imposed mesh.

However, `ELEM TRI3` is specified in the OPTION directive, the surface will contain only 3-node triangles.

Illustration:





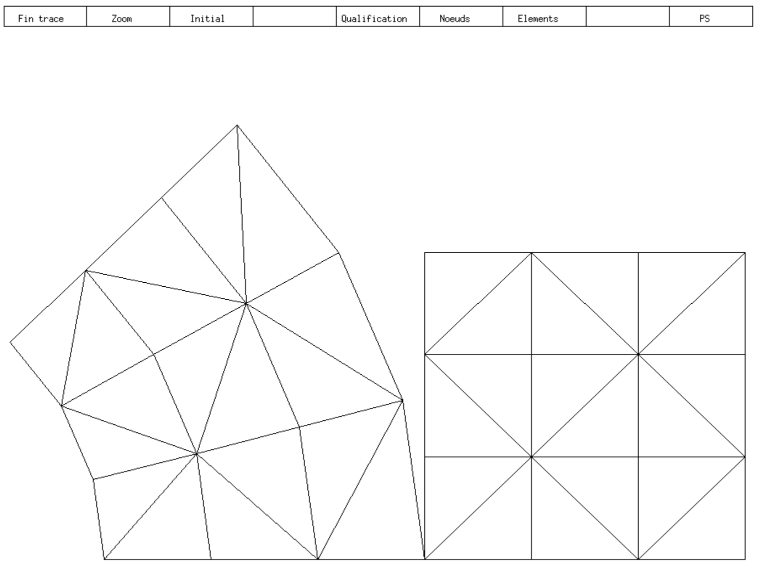
It would also have been possible to use 8-node quadrangles or 6-node triangles if ELEM QUA8 or ELEM TRI6 had been specified in the OPTION directive.

The ROTA and TRANS operators make it possible to generate a surface from a line:

Example:

```
OPTI DIME 2 ELEM TRI3;
P1 = 0. 0.;
C1= 1. 0;
C2= 2. 0.
LI1 = C1 D 3 C2;
S1 = LI1 ROTA 3 45. P1;
S2 = LI1 TRANS 3 ( 0. 1.) ;
S2 = S2 PLUS ( 1 0);
```

illustration:



For S1, 45. is the angle of rotation in degrees, 3 the number of elements to be created around the circumference and P1 the point at the centre of the rotation of the surface.
For the surface S2, (1. 0.) stands for the translation vector and 3 the number of elements to be created on the side of the translation.

The mesh fineness is controlled, in these 2 surfaces, by the length of the segments composing the line LI1 and by the number of elements to be created on one side or by the density of the extreme points.

The DALLER operator makes it possible to mesh regularly the inside of a contour defined by 4 sides; the opposed sides have the same number of points.

The REGLER operator constructs a ruled surface lying on two lines.

The VOLUME operator creates volumes from surfaces.

The number of elements of a MAILLAGE object can be retreived using the NBEL operator.

Example:

```
NN1= NBEL S1;
```

3.4 Lesson 8 : GEOMETRICAL ELEMENTS

Here is the list of the elements that can be generated by meshing operators out of the context of a finite element formulation. There are two categories: linear and quadratic elements depending on whether the sides of the elements have a node in the middle or not.

linear elements

element	description
POI1	1-node point
SEG2	2-node line
TRI3	3-node triangle
QUA4	4-node quadrangle
TET4	4-node tetrahedron
PRI6	6-node prism
PYR5	5-node pyramid
CUB8	8-node cube
RAC2*	4-node element transitioning some SEG2
LIA3*	6-node element transitioning some TRI3
LIA4*	8-node element transitioning some QUA4

quadratic elements

element	description
SEG3	3-node line
TRI6	6-node triangle
QUA8	8-node quadrangle
TE10	10-node tetrahedron
PR15	15-node prism
PY13	13-node pyramid
CU20	20-node cube
RAC3*	6-node element transitioning some SEG3
LIA6*	12-node element transitioning some TRI6
LIA8*	16-node element transitioning some QUA8

* The transition elements make it possible to define double-node lines or surfaces. These double nodes have the same coordinates but not the same unknowns. This category of elements is required when one wishes to transition meshes with formulations where the degrees of freedom are different.

3.5 Lesson 9 : THE CONFONDRE AND ELIM DIRECTIVES

In a meshing process, it may occur that two different parts of the mesh be constructed separately but have points in common.

If the nodes are known by name, the **CONFONDRE** directive should be used.

Example:

```
CONF C1 C2;
```

C1 and C2 are the nodes to be merged.

Otherwise, it is requested to use the **ELIM** directive.

Example:

```
ELIM SU1 SU2 (CRITERE);
```

SU1 and SU2 are the names of two meshes. CRITERE is given as argument only if the density of the points is not known, otherwise only the points separated by less than one tenth of the current density will merge.

Remark:

Generally speaking, one should be cautious when using those two directives. It is better to structure the set of data so as to avoid using them as much as possible.

If, for instance, two surfaces have a line in common, it is preferable to create the line first, then the two surfaces from that line, rather than create the surfaces and use ELIM between them.

3.6 Lesson 10 : THE SORTIR AND LIRE DIRECTIVES

It is possible, by means of the SORTIR directive, to write a mesh or a part of a mesh on a logical file defined by the OPTION directive.

Example:

```
*construction of the GEO mesh
.........;
.........;
OPTI SORT 15 ;
SORTIR GEO;
FIN;
```

On the other hand, it is possible, by means of the LIRE directive, to read a mesh from a logical file defined by the OPTION directive.

Example:

```
OPTI LIRE 15;
LIRE GEO;
MM=MODL GEO MECANIQUE ELASTIQUE COQ2;
....;
```

4. ELASTIC CALCULATION

4.1 Lesson 11 : REPRESENTATION OF FIELDS

4.1.1 Fields by points

The first way to represent a field consists in defining it by its values at the nodes of the mesh: it is called a CHPOINT type object or field by points.

Here is the simplest way of creating it:

Example:

```
C1 = 0 0 ;
CHP1 = MANU CHPO C1 2 UX 1. UY 3.;
```

A field by point with two components named UX and UY and the values of which are 1. and 3. are created on the point C1.(**A name of component cannot exceed 4 letters**).

A CHPOINT type object can also be created from a set of points as follows:

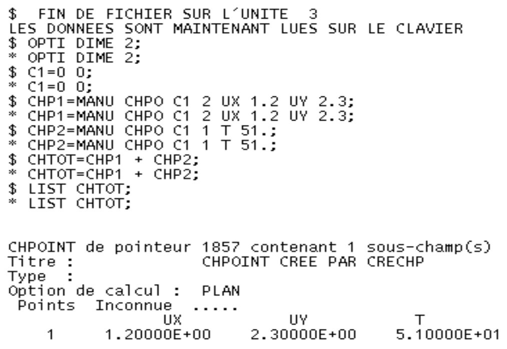
Example:

```
CHP2 = MANU CHPO ( C1 ET C2 ET ..) 2 UX ( PROG .1 .2 ..) UY ( PROG 1. 2. ..);
```

In this case, the names of the components must be followed by a progression containing as many floatings as there are points in the considered set of points.

The usual operations such as sums and substractions are possible, whatever the geometrical supports, the number and the names of components of the CHPOINTs may be.

Example:



```
$  FIN DE FICHIER SUR L´UNITE  3
LES DONNEES SONT MAINTENANT LUES SUR LE CLAVIER
$ OPTI DIME 2;
* OPTI DIME 2;
$ C1=0 0;
* C1=0 0;
$ CHP1=MANU CHPO C1 2 UX 1.2 UY 2.3;
* CHP1=MANU CHPO C1 2 UX 1.2 UY 2.3;
$ CHP2=MANU CHPO C1 1 T 51.;
* CHP2=MANU CHPO C1 1 T 51.;
$ CHTOT=CHP1 + CHP2;
* CHTOT=CHP1 + CHP2;
$ LIST CHTOT;
* LIST CHTOT;


CHPOINT de pointeur 1857 contenant 1 sous-champ(s)
Titre :             CHPOINT CREE PAR CRECHP
Type  :
Option de calcul :  PLAN
 Points  Inconnue  .....
              UX            UY            T
    1     1.20000E+00    2.30000E+00    5.10000E+01
```

It is also possible to multiply, divide these CHPOINT type objects by a floating, or to raise them to a power:

Example:

```
CHP5 = CHP1 *2;
CHP6 = CHP1 **2;
CHP7 = CHP1 / 2.;
```

Moreover, two fields by points can be joined by means of the ET operator. The point and the component which are common to the two fields are taken, and their corresponding values are added.

The names of components are either chosen by the user, or arbitrarily determined by the operators that create the objects.
The name of a component can be modified by means of the **NOMC** operator if the field by point only contains one component.

Example:

```
CHP8 = MANU CHPO C1 1 UZ 10;
CHP8 = NOMC T CHP8;
```

CHP8 is overwritten and the name of its component UZ is turned into T.

It is possible to extract a one-component CHPOINT from a multiple-component CHPOINT by specifying the name of this new component by means of the **EXCO** operator.

Example:

```
CHP9 = EXCO UX CHP1 T;
```

4.1.2 Fields by elements

Another way of representing a field consists in defining the field by its values in the different elements of the mesh: this is what is called a MCHAML type object (former CHAMELEM) or field by element.

In each element, the field can lie respectively on the:

- nodes
- stiffness integration points

- mass integration points
- centres of gravity
- stress calculation points

Here is the simplest way of creating it:

Example:

```
CHAM1 = MANU CHML GEO G 9.81 ‘TYPE’ GRAVITE;
```

CHAM1 is an MCHAML type field by elements with a single component G, a GRAVITE subtype pertaining to the GEO mesh.

In the same way as for the fields by points, it is possible to apply the usual operations of algebraic calculation to these fields:

+, -, *, /, **

The **ET** operator makes it possible to merge fields by elements of the same subtype.

4.2 Lesson 12 : ELASTIC CALCULATION

In order to perform an elastic calculation (assuming that the mesh object GEO1 exists), one must conform to the following stages:

a) **definition of the type of calculation and finite element formulation**.

Example:

```
MO = MODL GEO1 MECANIQUE ELASTIQUE TRI3;
```

The MODL operator makes it possible to define:

- the type of formulation, in this instance MECANIQUE (mechanic).
- the type of linear behavior, in this instance ELASTIQUE (elastic) and ISOTROPE (isotropic) by default
- the type of non-linear behavior (if necessary for the calculation)
- the type of finite element(s) to be used, TRI3.

MO is a MCHAML type object or “new chamelem” .

MODL groups together in one stage the former data preparation MODELE and AFFE.

b) **creation of the material field**:

Example:

```
MA1 = MATR MO YOUN 2E11 NU 0.3;
```

The MATR operator (former MATE) constructs the material field. This field must contain the additional characteristics of the elements when necessary.

They can be added into MA1 by means of MATR or using the CARB operator (see lesson 14).

Example:

```
MA1=MATR MO YOUN 2E11 NU 0.3 EPAI 0.001;
    or
CA1=CARB MO EPAI 0.001;
MA1=MA1 ET CA1;
```

c) **definition of the structure stiffness**

The RIGI operator is used.

Example:

```
RI1 = RIGI MO MA1;
```

d) **boundary conditions**

Example:

```
CL1 = BLOQU DEPL C1;
```

The BLOQU operator constructs the stiffness associated with conditions of imposed values on the unknowns of a discretized problem. The DEPL key word constrains all the displacement d.o.f of the point C1.
This stiffness will be added to the structure stiffness.

e) **loading**

The loading can be defined by means of the FORCE and CHARGEMENT operators.

Example:

```
FO1 = FORC (0. 1.) C2;
```

f) **resolution of the linear system**

The RESOU operator can then be used as follows:

Example:

```
RI2 = RI1 ET CL1;

DE1 = RESOU RI2 FO1;
```

The result of RESOU is a displacement CHPOINT. Once calculated, this field must be handled to deduce the stresses.

Example:

```
SI1 = SIGMA MO MA1 DE1;
```

7.3. Lesson 13 : CALCULATION IN IMPOSED DISPLACEMENTS

Instead of applying a force, it is possible to impose a displacement. It is required to call on the DEPI operator.

Example:

```
MO=MODL ....
MA1=MATR MO ...
RI1=RIGI ....
CL1=BLOQUE C1 DEPL;
CL2=BLOQUE C2 UX;
FO2=DEPI CL2 1;
```

DEPI creates a force field which imposes the value 1 to the displacement UX of the C2 object.
This field must be added to the other existing forces.

The system is solved in the same way as in lesson 12.

Example:

```
RI2 = RI1 ET CL1 ET CL2;
DE1 = RESOU RI2 FO2;
....
```

Remark:

- when displacements are imposed at one point, the constraint stiffness generated by the BLOQ operator must be added to the stiffness matrix.

4.4 Lesson 14: ELEMENTS REQUIRING ADDITIONAL CHARACTERISTICS

They are elements whose geometrical description cannot be entirely done with the MAILLAGE type objects. The list of elements of this type and both the compulsory and optional characteristics (in italics) are given in Table C.

These characteristics may be added in MATR or in an object (CARACTERISTIQUE subtype) created by CARB which is combined with the object created by MATR.

The elastic calculation will take the following form (for COQ3 elements):

Example:

```
MO=MODL GEO MECANIQUE ELASTIQUE COQ3;
MA=MATR MO YOUN 2E11 NU 0.3 ;
CA1=CARB MO EPAI 0.2;
MA1=MA ET CA1;
RI1 = RIGI MO MA1;
CL1=BLOQ DEPL L1;
RI2=RI1 ET CL1;
FO=FORCE (0. 1.) P1;
DE=RESOU RI2 FO;
SI1=SIGMA MO MA1 DE;
```

We could have written:

Example:

```
MA=MATR MO YOUN 2E11 NU 0.3 EPAI 0.2;
```

For POUT elements, the syntax can be the following:

Example:

```
CA1 = CARB MO SECT 5.2 INRY 10.4 INRZ 20. TORS 25.;
```

SECT, INRY, INRZ are the section and the different inertias of the beam.

element	**characteristic(s)**
COQ2, COQ3, COQ4 DKT	EPAI shell thickness *ALFA* plasticity criterion *EXCE* offset
COQ6, COQ8	EPAI shell thickness *EXCE* offset
BARRE	SECT cross section
POUTRE	SECT cross section INRY inertia with respect to the local axis Oy INRZ inertia with respect to the local axis Oz TORS twisting inertia *SECY* reduced section with shear stress *SECZ* reduced section with shear stress *VECT* vector of local axis *DX DY DZ* : distances for the calculation of stresses from moments in plasticity
TUYAU	EPAI thickness RAYO external radius *RACO* radius of curvature *VECT* vector of local axis *PRES* internal pressure
HOMOGENEISE	SCEL enlarged elementary cell SFLU fluid area in enlarged cell EPS pas tubulaire of the medium NOF1 norm modal tube/norm pressure NOF2 ratio between the scalar product of the modal deformed shape and the modal deformed shape of pressure, and the square of the norm of pressure
LINESPRING	EPAI shell thickness FISS notch depth VX, VY, VZ: components of the vector normal to the plane of the shell

element	**characteristic(s)**
TUYAU FISSURE	EPAI thickness RAYO pipe external radius ANGL crack total opening in degrees VX, VY, VZ: component of the pipe vector-axis VXF, VYF, VZF: orientation of the crack
RACCORD	For fluid-structure transition elements, it is required to know the position of the fluid with respect to the transition element. For this reason, the geometrical object will be given after the LIQU key word.

Table C

5. USE OF RESULTS

5.1 Lesson 15 : HOW TO USE THE RESULTS?

Having performed a calculation, the user is usually left with objects such as a stress field (MCHAML type) or a displacement field (CHPOINT type).

The best way to proceed would consist in printing these objects, but there is a risk of being overwhelmed by the large quantity of data.

As for the stress MCHAML, it is possible to calculate and print a few useful entities such as:

- Von Mises equivalent stress with the VMIS operator.
- the principal stresses with PRIN.
- a given component pertaining to a field may be extracted with EXCO.
- the support of a stress MCHAML or displacement CHPOINT may be turned into a smaller support by means of REDU.
- the numerical value of a component located at a specific point may be retreived by means of EXTR.
- the maximum and minimum values of a field may be obtained with MAXI and MINI.
- the norms of objects may be calculated with the XTX operator and the norm resulting from the difference between two stress or displacement fields may also be calculated to check, for instance, the discrepancy between the object obtained by calculation and a reference solution.
- the reactions may be estimated at the supports using the REAC operator.
- resultants may be calculated with the RESU operator.

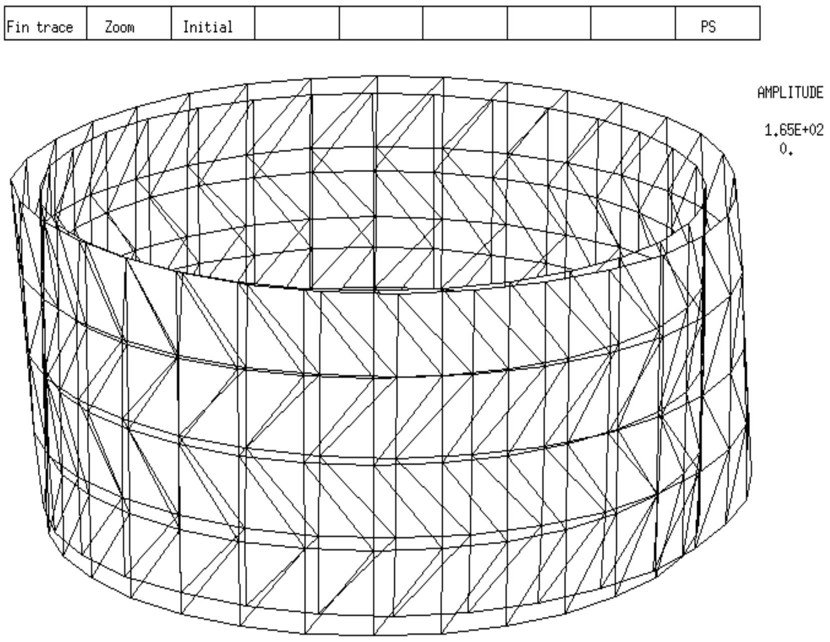
5.2 Lesson 16 : PLOTTING OF RESULTS

There are several types of plots:

- plot of deformed objects:

It is, for instance, the method used for showing the difference between the structure with loading and that without loading. For this, two DEFORMEE type objects must be created using the DEFO operator, the one with a null amplification coefficient, the other with a non null amplification coefficient. Then the union of these two objects is plotted.

Illustration:



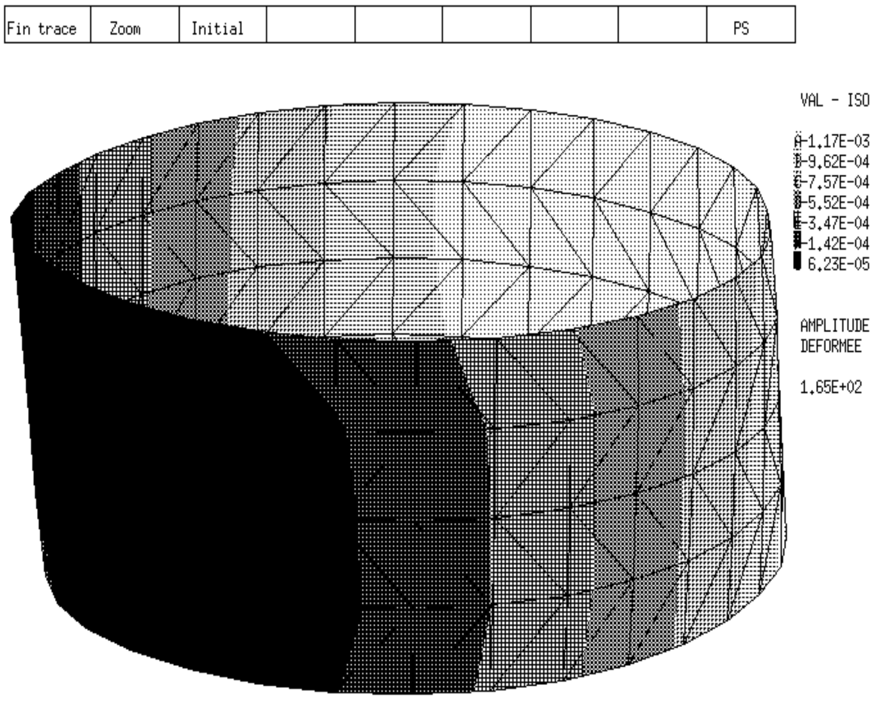
- plot of isovalues for a CHPOINT or MCHAML type object

It is requested to extract a field with one component - that which is to be plotted - by means of the EXCO operator; then TRACE will be used.

- plot of an MCHAML type object from a deformed object

It consists in combining the two previous types.

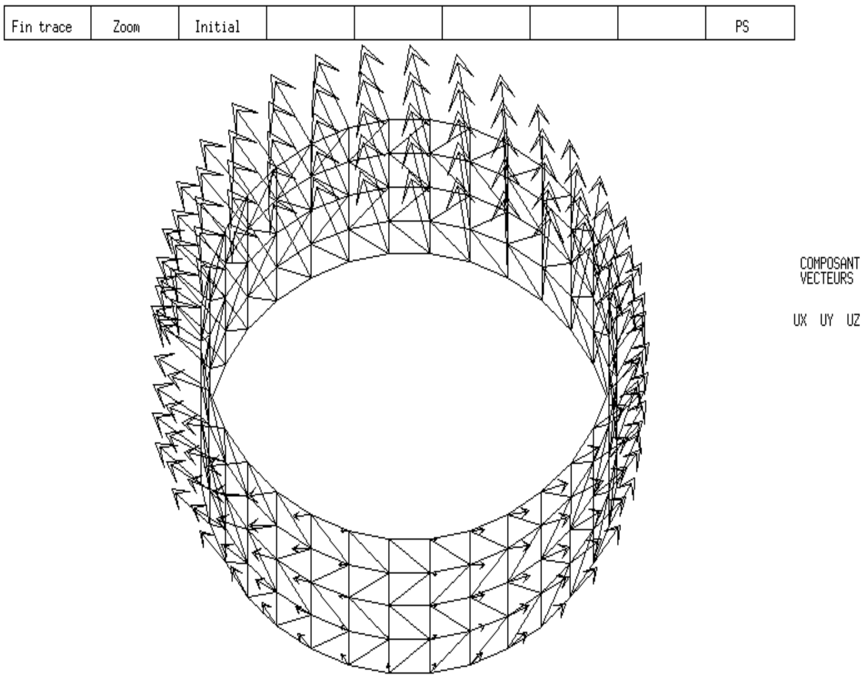
Illustration:



- plot of a VECTEUR type object

Small arrows may be associated with a CHPOINT by means of the VECT operator. This allows, for instance, a displacement field to be displayed.

Illustration



5.3 Lesson 17 : BACKUP AND RETREIVAL

CASTEM2000 makes it possible to store results and to retreive them by means of the SAUVER and RESTITUER operators.

Several objects can be saved and one can choose to save and retreive with or without format to avoid problems of compatibility between computers.

The SAUVER operator saves the objects specified by the user as well as those used to construct these objects; (see lesson 20)

SAUVER and RESTITUER are used as follows:

Example:

```
OPTI SAUV ‘FORMAT’ ‘data.sortgibi’;
SAUV ‘FORMAT’ MAT1 DE1;
```

or

```
OPTI SAUV ‘data2.sortgibi’;
SAUV MAT1 DE1;
```

depending on whether one saves a formatted or a non formatted file.

Likewise, for RESTITUER :

Example:

```
OPTI REST ‘FORMAT’ ‘data.sortgibi’;
REST;
```

or

```
OPTI REST ‘data2.sortgibi’;
REST;
```

6. A FEW DISTINCTIVE FEATURES OF CASTEM2000

6.1 Lesson 18 MCHAML TYPE OBJECTS

They replace the CHAMELEM type objects which are connected with the AFFECTE type objects.

They can store a wide variety of data.

They are subdivided in several subtypes. The main subtypes are:

-GRAVITE	: scalar at centre of gravity
-NOEUD	: scalar at the nodes
-RIGIDITE	: scalar at the stiffness integration points
-MASSE	: scalar at the mass integration points
-STRESSES	: scalar at the stress points
-DEPLACEM	: displacements
-FORCES	: forces
-CONTRAIN	: stresses
-DEFORMAT	: strains
-MATERIAU	: material
-CARACTER	: characteristics
-MAHOOKE	: Hooke’s matrix
-VARINTER	: internal variables
-TEMPERAT	: temperature

6.2 Lesson 19 : ELEMENTARY AND COMPOSED OBJECTS

In CASTEM2000, both elementary objects and objects composed of several elementary objects can be manipulated.

When, for instance, a surface is meshed only with triangles, the object is an elementary object. If, on the other hand, that surface is meshed with both quadrangles and triangles, the object is composed of two elementary objects.

This breakdown into elementary objects concerns the objects that are directly or implicitely connected with a mesh, for instance the MCHAML or RIGIDITE type objects.

Theses two notions are tied to the use of the ET operator (which allows several elementary objects to be merged for the creation of a composed object) on the one hand, and the REDU operator (which allows an elemenatary object to be extracted from a composed object) on the other.

6.3 Lesson 20 : RELATIONS BETWEEN OBJECTS

Some objects are closely related.

The relations depend on the computer structure of objects. They are summarized in the following diagram:

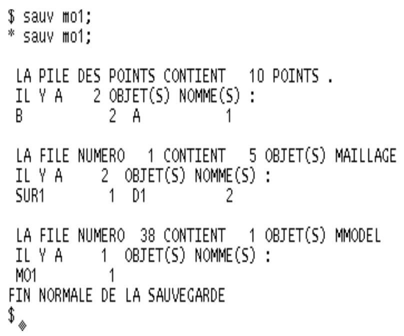
$$\begin{tikzcd}
 & & \boxed{\text{POINT}} \arrow[d] & \\
 & & \boxed{\text{MAILLAGE}} \arrow[dll] \arrow[dl] \arrow[d] \arrow[dr] & \\
\boxed{\text{CHPOINT}} & \boxed{\text{MMODEL}} & \boxed{\text{RIGIDITE}} & \boxed{\text{MCHAML}}
\end{tikzcd}$$

A CHPOINT type object is connected with the MAILLAGE and POINT type objects which had been used to construct it.

This notion is important when one wishes to handle objects (removal, modification, backup).

If a MMODEL type object is saved, the MAILLAGE and POINT type objects connected with it will also be saved.

Illustration:



```
$ sauv mo1;
* sauv mo1;

 LA PILE DES POINTS CONTIENT   10 POINTS .
 IL Y A    2 OBJET(S) NOMME(S) :
 B          2  A          1

 LA FILE NUMERO   1 CONTIENT   5 OBJET(S) MAILLAGE
 IL Y A     2  OBJET(S) NOMME(S) :
 SUR1       1  D1         2

 LA FILE NUMERO  38 CONTIENT   1 OBJET(S) MMODEL
 IL Y A     1  OBJET(S) NOMME(S) :
 MO1        1
FIN NORMALE DE LA SAUVEGARDE
$
```

6.4 Lesson 21 : REPETITIVE AND ALTERNATE EXECUTIONS

6.4.1 Repetitive executions

It merely consists in using loops in the GIBIANE language.

Example:

```
REPETER BOUC1 10;
......
......
......
FIN BOUC1;
```

Some natural applications stemming from these two instructions concern of course the non linear algorithms in mechanical analysis.

In order to calculate Euler approximation you would write, for instance:

Example:

```
NN=0;
EXP=1.;
REPETER BOUC1 50;
NN = NN +1;
RE = 1 / ( FLOTTANT NN);
EXP=EXP + RE;
FIN BOUC1;
EULER=EXP - (LOG NN);
```

6.4.2 Alternate executions

The directives SI, SINON, FINSI are used for tests. The REPETER and FIN instructions can be used simultaneously with the SI, FINSI and QUITTER instructions.

Let us assume that, in the loop, there is a LOGIQUE BOL1 type object checking the output from the loop. The loop will be written as follows:

Example:

```
REPETER BOUC2 10;
* loop internal instructions
```

```
SI BOL1;
QUITTER BOUC2;
FINSI;
* next instructions
FIN BOUC2;
```

6.5 Lesson 22 : PROCEDURES

The fact that CASTEM2000 is provided with numerous operators sometimes entails a drawback: the sets of data may be long and complex; one will soon realize that some sequences of instructions are used several times in the same set of data or by several users.

Hence the idea of gathering these instructions together into a specific structure: the procedure.

It takes the following form:

- in the declarative form:

```
DEBPROC NOM ARG1*TY1 ARG2*TYPE2 ARG3*TYP3 ARG4*TYP4 (..);

*series of instructions

FINPROC SORT1 SORT2 SORT3 (..);
```

When adjusting this procedure, make sure that this pack of instructions is located before the place where it is wished to be used.

- in calling order:

RESU1 RESU2 RESU3 (..) NOM DONN1 DONN2 DONN3 DONN4 (..);

Afterwards this procedure will be used as an operator.

The following example shows how to operate a simple procedure turning coordinates into polar coordinates.

Example:

```
DEBPROC POLAIRE X1*FLOTTANT X2*FLOTTANT;
RR = ( X1*X1+X2*X2)**0.5 ;
THE = ATG X1 X2;
FINPROC RR THE;
```

This procedure will then be used as follows:

```
RO TET = POLAIRE A B ;
```

Another simple example is given by the LIREFLOT procedure which makes it possible to read, in interactive mode, a floating number ranged between two given boundaries.

The procedure is written as follows:

```
DEBPROC LIREFLOT UMIN*FLOTTANT UMAX*FLOTTANT;
REPETER BLOC1;
OBTENIR FL*FLOTTANT ;
SI ((>EG UMIN) ET (<EG FL UMAX));
QUITTER BLOC1;
FINSI;
MESSAGE ‘DONNEZ UN NOMBRE COMPRIS ENTRE ‘ UMIN ‘ ET ‘UMAX;
FIN BLOC1;
FINPROC FL;
```

It will be used as follows:

```
XX=LIREFLOT 0. 1.E10;
```

It allows interactive softwares to be easily structured in CASTEM2000 by means of the OBTENIR and MESSAGE operators.

6.6. Lesson 23 : TABLE TYPE OBJECTS

Within the context of the CASTEM2000 objects, it is required to:

- assemble a series of objects under the same name;
- index that series of objects;
- allocate a type to these indices (FLOTTANT, ENTIER, MOT, ...).

The TABLE type object fulfils this function.

This object is used as follows:

Example:

```
*creation of the table
 MAT1 = TABLE ;
*the element of index 1 equals 5
 MAT1.1 =5. ;
* the element of index 1 i.e. 5 is printed
 LIST MAT1.1;
```

the table may also be indexed using key words:

Example:

```
MAT2=TABLE;
M1= MOT ‘ESS’;
M2=MOT ‘TYP’;
MAT2.M1=1.8;
MAT2.M2=2.3;
LIST (MAT2.M1);
LIST (MAT2.M2);
```

Remark:

- Several types of indices may be used at once in a table.

6.7. Lesson 24 : MANIPULATION OF THE COMPONENTS OF CHPOINT OR MCHAML

Complex operations may be performed on MCHAML or CHPOINT type objects by characterizing the components of these objects.

It is possible, for instance, to calculate the divergence of a displacement field DEP1 in the following way:

Example:

```
EPS1=EPSI MODL1 DEP1;
EP10=EXCO EPS1 EPXX;
EP20=EXCO EPS1 EPYY;
EP30=EXCO EPS1 EPZZ;
TR1 = EP10 + EP20 + EP30;
```

The corresponding tensorial product may also be calculated from a stress field SI1 and a gradient field GRD1.

First the components of the 2 fields will be retreived.

Example:

```
SIXX=EXCO SI1 SMXX;
SIYY=EXCO SI1 SMYY;
SIXY=EXCO SI1 SMXY;

GRXX=EXCO GRD1 UX,X;
GRXY=EXCO GRD1 UX,Y;
GRYX=EXCO GRD1 UY,X;
GRYY=EXCO GRD1 UY,Y;
```

Then the products required for obtaining the components of the tensorial product will be carried out:

```
T1=(SIXX*GRXX) + (SIXY*GRYX);
T2=(SIXY*GRXX) + (SIYY*GRYX);
T3=(SIXX*GRXY) + (SIXY*GRYY);
T4=(SIXY*GRXY) + (SIYY*GRYY);
```

6.8. Lesson 25 : HOW TO USE THE GEMAT (9.3 release)

The user can specify the memory space required for his calculation or the translation parameters if he is a developer.

For this, he must alter different parameters contained in a file which is called as soon as CASTEM2000 is executed.

6.8.1 The Parameter file

Usually it is an ASCII data file (EBCDIC on IBM) which can be created by an edit program.

According to the operating system, the parameter file is a **fortran file number 99** or is named **PARAM**.

On CRAY, the parameter file is replaced with a string placed at the beginning of the set of data.

It contains data written as follows:KEY WORD

KEY WORD = value.

If there are several parameters, the separating character is a comma.

Example :

```
BUF=20000,NTRK=100,LTRK=2048,DUMP
```

Two types of parameters must be supplied:

Execution parameters **Translation parameters**

6.8.1.1 Execution parameters.

ESOPE and BUF

The ESOPE parameter = fixed eee, in number of words eee, size of the memory space which must be available for GEMAT. If eee words are not available, the program running will be stopped.

If there is no ESOPE parameter, the maximum number of words available will be allocated to GEMAT; if necessary, the value bbbb of the parameter BUF = bbbb will be substracted from GEMAT.

The parameter BUF = bbbb stores bbbb words in memory. By default BUF= 0.

ZERMEM

The parameter ZERMEM = NON (no) prevents GEMAT, at the time of initialization, from setting back to zero the memory space which has been allocated to it. This option will be used only if it is certain that this memory space is already at zero. By default ZERMEM = OUI (yes).

LTRK and NTRK

The memory overflow file GEMAT is direct access; it includes NTRK = nnn blocks of LTRK = lll words each.

If there is no NTRK parameter or if it equals 0, there will be no disk memory overflow.

If nnn is negative in NTRK = nnn, the absolute value will be taken into account, but the memory management algorithms will be those previous to the 9.1 release of GEMAT.

To make sure that the space in this memory overflow file is enough, the user will allow a requirement of nnn x lll words; this corresponds to twice the maximum requirement of all the segments existing at a given moment of the program execution.

OFILE

The OFILE parameter sets the fortran number of the memory overflow file when the value of NTRK is different from zero.

DUMP

During the execution of an ESOPE subprogram, the memory management subprograms may detect an abnormal situation and stop the execution after having printed a diagnosis. For getting a DUMP at that very moment, the DUMP parameter will be used.

VERACT

During the execution of an ESOPE subprogram, it will be difficult to detect the error made while using the variable of a disabled segment. Most of the time, such a situation will entail a serious failure relative to the program execution:

adressing error

domain error

violation ...

In order to avoid these reactions, the option VERACT = NON (no) should be used temporarily .

By default VERACT = OUI (yes).

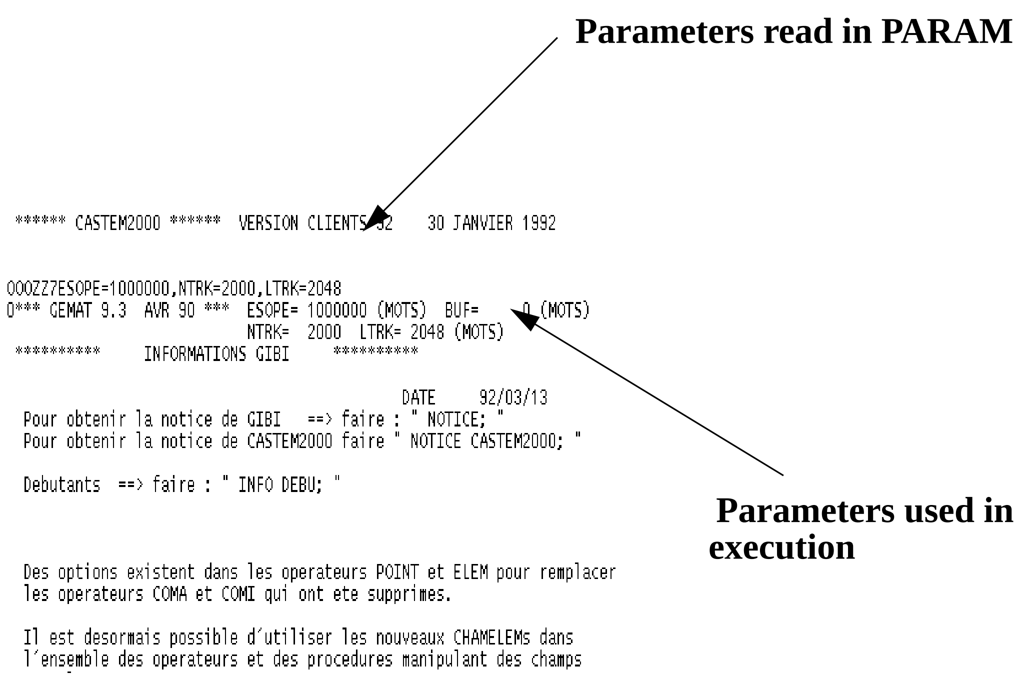
Example of a PARAM file:

ESOPE=1000000,NTRK=2000,LTRK=2048

Only the first line of the PARAM file is taken into account.

It is checked whether the PARAM file parameters have been taken into account at the start of the program execution:

Illustration:



```
 ****** CASTEM2000 ******  VERSION CLIENTS 92    30 JANVIER 1992


OOOZZ7ESOPE=1000000,NTRK=2000,LTRK=2048
0*** GEMAT 9.3  AVR 90 ***  ESOPE= 1000000 (MOTS)  BUF=     0 (MOTS)
                            NTRK=  2000  LTRK= 2048 (MOTS)
 **********     INFORMATIONS GIBI     **********

                                                 DATE     92/03/13
  Pour obtenir la notice de GIBI   ==> faire : " NOTICE; "
  Pour obtenir la notice de CASTEM2000 faire " NOTICE CASTEM2000; "

  Debutants  ==> faire : " INFO DEBU; "



  Des options existent dans les operateurs POINT et ELEM pour remplacer
  les operateurs COMA et COMI qui ont ete supprimes.

  Il est desormais possible d´utiliser les nouveaux CHAMELEMs dans
  l´ensemble des operateurs et des procedures manipulant des champs
```

6.8.1.2 Translation parameters

Specific to the ESOPE translator:

FORT

Makes it possible to generate a fortran language adapted to a selected computer by specifying FORT = xxx. xxx can be one of the following values:

IBM, VAX, CRAY, SUN, CONVEX, PRIME, FPS, UNIVAC, SEL, HP9000, NOSVE, NORSK ...

VERCALL

Makes it possible to generate a fortran language containing or not the characteristics for checking, at the time of the execution, whether an Esope subprogram (containing SEGxxx instructions) has been called by CALL with a variable pertaining to a segment in argument.

- VERCALL = OUI (yes) (default) Checking of the CALLs.

- VERCALL = NON (no) No checking of the CALLs.

VERSEG

Makes it possible to generate a fortran language containing or not the characteristics for producing, at the time of the execution, improved error messages for failures occurring during the execution of SEGxxx instructions.

- VERSEG = OUI (yes) (Default) possible improved messages

- VERSEG = NON (no) possible non improved messages

NORM

See chapter “CISI extensions” of the Development Guide (Report CEA / DMT.92.300) in which extensions to the Esope language are described.

- NORME = DEDR . Default option. The CISI extensions are refused by the ESOPE translator.

- NORME = CISI . The CISI extensions are accepted.

Example of PARAM file:

```
ESOPE=1000000,FORT=SUN
```

7. MORE MECHANICS

7.1. Lesson 26 : BOUNDARY CONDITIONS

It is possible to impose various boundary conditions, with the following operators:

- the BLOQUE operator allows the specific degrees of freedom to be constrained in the given directions

- the SYMT operator allows boundary conditions of symmetry to be specified with respect to a plane or a straight line

- the ANTI operator allows boundary conditions of antisymmetry to be specified with respect to a plane or a straight line

- the RELA operator makes it possible to impose any linear combination of displacements at different points: this operator is especially useful when you will have the displacements of two nodes identical or when you will have the displacements and the rotations compatible with a junction between shell and massive elements.

  An interesting option of the RELA operator is the key word CORI:
  it makes it possible to impose a stiff body motion to a set of nodes.

Besides, the RELA and BLOQUE operators allow unilateral conditions of type Ux > var to be input.

$U_x > \text{var}$

7.2. Lesson 27 : THERMAL LOADINGS

Calculations with thermal loadings can be easily performed as follows:

We assume that the temperature field was first determined in the form of a TEMPERAT subtype MCHAML; let TX1 be this field...

Therefore it is possible to create the corresponding stress field by means of the THETA operator:

```
SI1 = THETA MODL1 MAT1 TX1;
```

Followed by the equivalent force field with the BSIGMA operator:

```
FO1 = BSIGMA MODL1 SI1;
```

Therefore it is possible to calculate the outcoming displacement field with RESOU :

```
RI1 = RIGI MODL1 MAT1 ;
CL1 = BLOQUE LI1 DEPL;
DE1 = RESOU ( RI1 ET CL1) FO1;
```

and the corresponding total stresses:

```
SI2 = SIGMA MODL1 MAT1 DE1;
```

Finally it is required to substract the stresses of thermal origin to obtain the true stresses:

```
SIV = SI2 - SI1 ;
```

7.3. Lesson 28 : EIGEN FREQUENCIES AND MODES

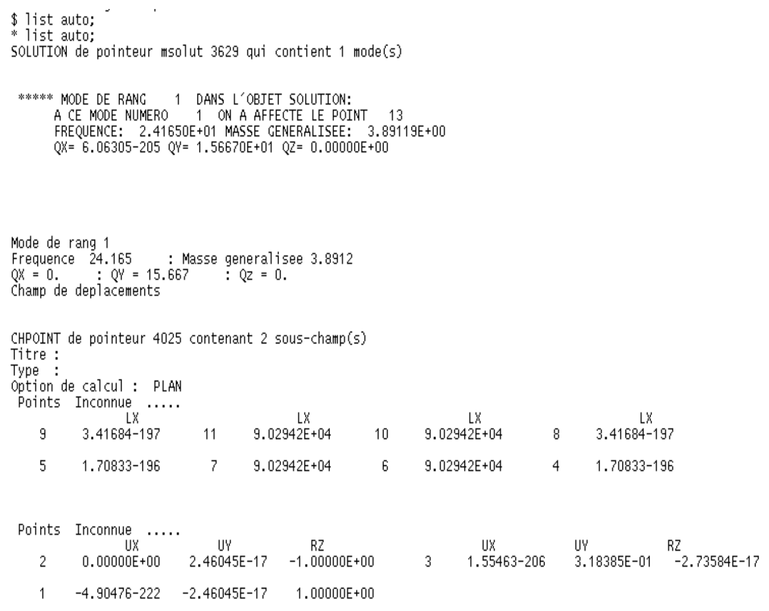
Eigen frequencies and modes can be calculated by means of the RIGI, MASSE and VIBRATION operators.

Example:

```
MA1 = MATR MO YOUN 2E11 NU 0.3 RHO 78000;
RI1 = RIGI MO MA1;
RI2 = RI1 ET CL1;
MAS1=MASSE MO MA1;
SO1=VIBR PROC ( PROG 20) RI2 MAS1;
```

SO1 is a SOLUTION type object (TABLE type if the key word TBAS is specified) which contains the eigen frequency and mode which are closer to 20 Hz.

Illustration:



```
$ list auto;
* list auto;
SOLUTION de pointeur msolut 3629 qui contient 1 mode(s)


 ***** MODE DE RANG    1  DANS L´OBJET SOLUTION:
      A CE MODE NUMERO    1  ON A AFFECTE LE POINT   13
      FREQUENCE:  2.41650E+01 MASSE GENERALISEE:  3.89119E+00
      QX= 6.06305-205 QY= 1.56670E+01 QZ= 0.00000E+00



Mode de rang 1
Frequence  24.165     : Masse generalisee 3.8912
QX = 0.     : QY = 15.667     : Qz = 0.
Champ de deplacements


CHPOINT de pointeur 4025 contenant 2 sous-champ(s)
Titre :
Type  :
Option de calcul :  PLAN
 Points  Inconnue  .....
               LX                     LX                     LX                     LX
    9     3.41684-197      11     9.02942E+04      10     9.02942E+04       8     3.41684-197

    5     1.70833-196       7     9.02942E+04       6     9.02942E+04       4     1.70833-196


 Points  Inconnue  .....
               UX           UY           RZ                    UX           UY           RZ
    2     0.00000E+00    2.46045E-17   -1.00000E+00       3     1.55463-206    3.18385E-01   -2.73584E-17

    1    -4.90476-222   -2.46045E-17    1.00000E+00
```

The algorithms used are:

- for the PROCHE option : algorithm of inverse iterations
- for the INTERVALLE option : research in a bandwidth
- for the SIMULTANE option : lanczos algorithm.

7.4. Lesson 29 : BUCKLING

Buckling is processed in the same way as for the calculation of eigen modes apart from the fact that the mass matrix is replaced with the matrix of initial stresses (calculated by the KSIGMA operator and multiplied by -1).

The result will be:

Example:

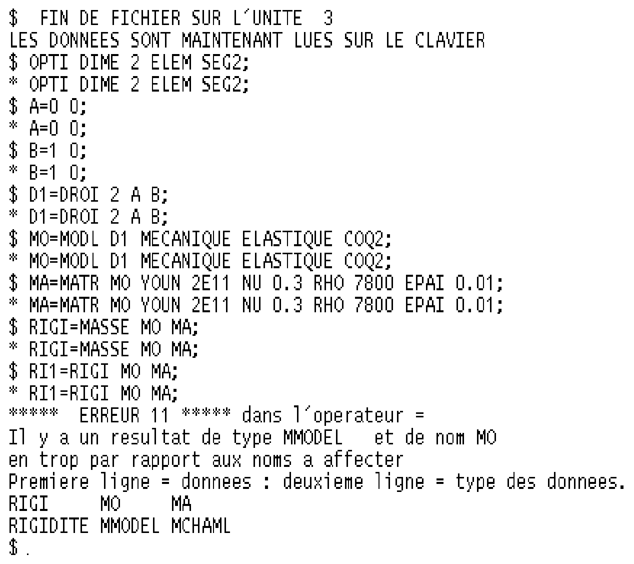
```
MA1=MATR MO YOUN 2E11 NU 0.3;
RI1= RIGI MO MA1;
FO=FORCE .....;
CL1=BLOQ .....;
RI2=RI1 ET CL1;
DE1=RESOU RI2 FO1;
SE1=SIGMA MO MA1 DE1;
KSE1=KSIGMA MO SE1 FLAM;
SO1=VIBR PROC (PROG 4.3) RI2 (-1*KSE1);
```

The result is therefore the buckling mode associated with the multiplicator coefficient closer to $(4.3)^2$.

8. LIST OF COMMON ERRORS

Use of the name of an object corresponding to the name of an operator

Illustration:

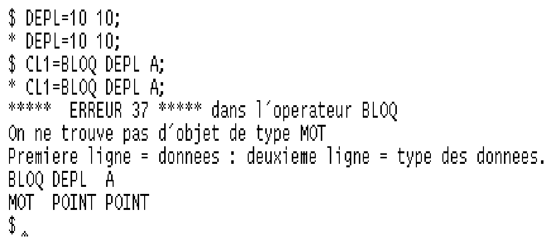


```
$  FIN DE FICHIER SUR L´UNITE  3
LES DONNEES SONT MAINTENANT LUES SUR LE CLAVIER
$ OPTI DIME 2 ELEM SEG2;
* OPTI DIME 2 ELEM SEG2;
$ A=0 0;
* A=0 0;
$ B=1 0;
* B=1 0;
$ D1=DROI 2 A B;
* D1=DROI 2 A B;
$ MO=MODL D1 MECANIQUE ELASTIQUE COQ2;
* MO=MODL D1 MECANIQUE ELASTIQUE COQ2;
$ MA=MATR MO YOUN 2E11 NU 0.3 RHO 7800 EPAI 0.01;
* MA=MATR MO YOUN 2E11 NU 0.3 RHO 7800 EPAI 0.01;
$ RIGI=MASSE MO MA;
* RIGI=MASSE MO MA;
$ RI1=RIGI MO MA;
* RI1=RIGI MO MA;
*****  ERREUR 11 ***** dans l´operateur =
Il y a un resultat de type MMODEL   et de nom MO
en trop par rapport aux noms a affecter
Premiere ligne = donnees : deuxieme ligne = type des donnees.
RIGI     MO     MA
RIGIDITE MMODEL MCHAML
$ .
```

The syntax analyzer can no longer recognize the name of the operator which the user tried to use. From now on RIGI is a RIGIDITE type object.

Use of the name of an object corresponding to the key word of an operator

Illustration:



```
$ DEPL=10 10;
* DEPL=10 10;
$ CL1=BLOQ DEPL A;
* CL1=BLOQ DEPL A;
*****  ERREUR 37 ***** dans l´operateur BLOQ
On ne trouve pas d´objet de type MOT
Premiere ligne = donnees : deuxieme ligne = type des donnees.
BLOQ DEPL  A
MOT  POINT POINT
$
```

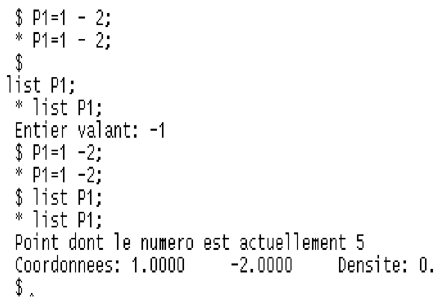
In this example, the name DEPL is not compatible with the key word DEPL allowing all the translation d.o.f. to be constrained.

Remark:

- In order to remedy to these two common errors, it is advisable to attribute names containing for instance one digit to the objects because the names of operators do not contain any.

Confusion between points and substraction

Illustration:

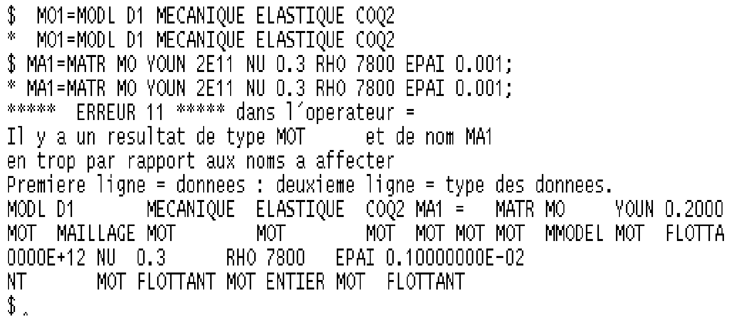


```
$ P1=1 - 2;
* P1=1 - 2;
$
list P1;
 * list P1;
Entier valant: -1
$ P1=1 -2;
* P1=1 -2;
$ list P1;
* list P1;
Point dont le numero est actuellement 5
Coordonnees: 1.0000     -2.0000     Densite: 0.
$
```

The first instruction generates an integer, the second generates a POINT type object

Use of an instruction without hyphen at the end

Illustration:

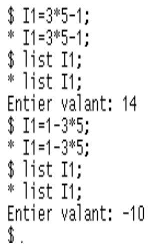


```
$  MO1=MODL D1 MECANIQUE ELASTIQUE COQ2
*  MO1=MODL D1 MECANIQUE ELASTIQUE COQ2
$ MA1=MATR MO YOUN 2E11 NU 0.3 RHO 7800 EPAI 0.001;
* MA1=MATR MO YOUN 2E11 NU 0.3 RHO 7800 EPAI 0.001;
*****  ERREUR 11 ***** dans l'operateur =
Il y a un resultat de type MOT      et de nom MA1
en trop par rapport aux noms a affecter
Premiere ligne = donnees : deuxieme ligne = type des donnees.
MODL D1       MECANIQUE  ELASTIQUE  COQ2 MA1 =   MATR MO     YOUN 0.2000
MOT  MAILLAGE MOT        MOT        MOT  MOT MOT MOT  MMODEL MOT  FLOTTA
0000E+12 NU  0.3      RHO 7800   EPAI 0.10000000E-02
NT       MOT FLOTTANT MOT ENTIER MOT  FLOTTANT
$
```

The syntax analyzer can no longer perform its decoding properly and the error message printed is that of the operator contained in the next line.

Rule of hierarchy between operators

Illustration:

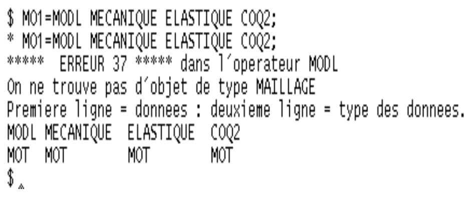


```
$ I1=3*5-1;
* I1=3*5-1;
$ list I1;
* list I1;
Entier valant: 14
$ I1=1-3*5;
* I1=1-3*5;
$ list I1;
* list I1;
Entier valant: -10
$
```

The rules of hierarchy between arithmetic operators do not follow the usual mathematical rules.

Operator used with an insufficient number of arguments

Illustration:

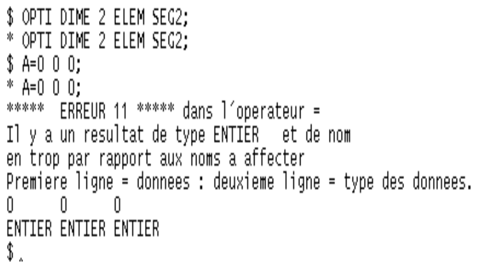


```
$ MO1=MODL MECANIQUE ELASTIQUE COQ2;
* MO1=MODL MECANIQUE ELASTIQUE COQ2;
*****  ERREUR 37 ***** dans l´operateur MODL
On ne trouve pas d´objet de type MAILLAGE
Premiere ligne = donnees : deuxieme ligne = type des donnees.
MODL MECANIQUE  ELASTIQUE  COQ2
MOT  MOT        MOT        MOT
$
```

In this case, there is always a message such as: “we cannot find any ... type object”

Operator used with an excessive number of arguments

Illustration:

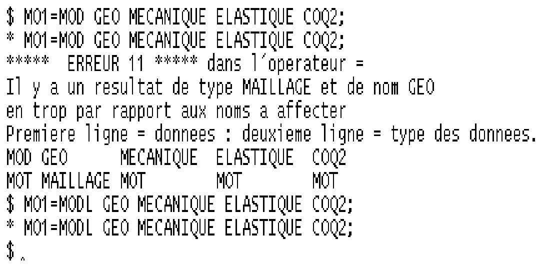


```
$ OPTI DIME 2 ELEM SEG2;
* OPTI DIME 2 ELEM SEG2;
$ A=0 0 0;
* A=0 0 0;
*****  ERREUR 11 ***** dans l´operateur =
Il y a un resultat de type ENTIER   et de nom
en trop par rapport aux noms a affecter
Premiere ligne = donnees : deuxieme ligne = type des donnees.
0      0      0
ENTIER ENTIER ENTIER
$
```

The message always takes the form “there is a ... type result too many with respect to the names to be allocated”

The first 4 letters of both the key words and the operators are tested.

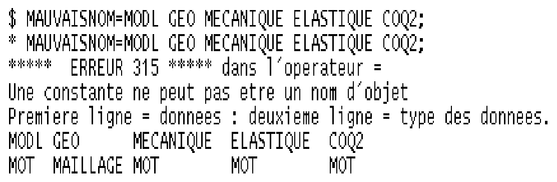
Illustration:



```
$ MO1=MOD GEO MECANIQUE ELASTIQUE COQ2;
* MO1=MOD GEO MECANIQUE ELASTIQUE COQ2;
*****  ERREUR 11 ***** dans l´operateur =
Il y a un resultat de type MAILLAGE et de nom GEO
en trop par rapport aux noms a affecter
Premiere ligne = donnees : deuxieme ligne = type des donnees.
MOD GEO      MECANIQUE  ELASTIQUE  COQ2
MOT MAILLAGE MOT        MOT        MOT
$ MO1=MODL GEO MECANIQUE ELASTIQUE COQ2;
* MO1=MODL GEO MECANIQUE ELASTIQUE COQ2;
$
```

8 characters of the names of objects are tested.

Illustration:



```
$ MAUVAISNOM=MODL GEO MECANIQUE ELASTIQUE COQ2;
* MAUVAISNOM=MODL GEO MECANIQUE ELASTIQUE COQ2;
*****  ERREUR 315 ***** dans l´operateur =
Une constante ne peut pas etre un nom d´objet
Premiere ligne = donnees : deuxieme ligne = type des donnees.
MODL GEO      MECANIQUE  ELASTIQUE  COQ2
MOT  MAILLAGE MOT        MOT        MOT
```