FEAP - - A Finite Element Analysis Program

Version 8.7 Contact Programmer Manual

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Chapter 1

Introduction

This manual is a short guide to describe the features of the *FEAP* contact algorithm. The contact algorithm comes with a small library of basic features. For the use of these existing features the algorithm can be treated as a *black box*. When implementing new contact formulations the algorithm may be treated partially as a black box. New contact formulations can be added similar to the way continuum elements are added; hence, the user is not directly involved in the management of arrays for history variables or in modifying some crucial data (e.g., the column height vector for the global stiffness matrix).

In the next paragraphs the basic input data organization is described. Moreover, the basic structure of the algorithm and the currently available features also are described. Finally, information is provided for users who are interested in implementing new features or their own contact formulation.

This manual is not intended to provide any detailed information about contact solution algorithms. However, it is assumed that the reader has some knowledge about how contact algorithms are solved using the finite element method. For example, some information on so called *node to surface contacts* may be found in reference [1] with additional information in references [2] to [58].

1.1 Description of basic characteristics

Independent modules are used in *FEAP* to define contact interactions between surfaces. The data input for a contact interaction is provided *after* the initial mesh is defined. Accordingly, contact data *must* follow the `END` mesh command and any `TIE` mesh manipulation commands. The description of the contact algorithm is initiated by a `CONT`act command and is terminated by an `END` command. Contact input data is divided into three main categories:

1. `SURF`ace definitions.

   The `SURF`ace definition is purely a geometrical description of any surfaces which may be considered in any analysis involving contact between bodies. A surface is defined as a group of element *facets*. A facet may be any geometric shape which the *contact formulation* can consider. Facets may be single *nodes*, edges of the *finite elements* defining each body, and/or faces of the finite elements.

2. `MATE`erial parameter definition.

   The `MATE`erial parameter definition defines the constitutive characteristics of a contact surface. For analyses in which there is no constitutive equation for the normal direction but frictional behavior for sliding, the pseudo material model is called *standard* and defined by a `STANdard` command.

3. `PAIR` definitions.

   The `PAIR` definition defines two surfaces which can interact, as well as, the associated material constitution(s) and details for the solution algorithm to be employed.

FEAP uses the surface and material data sets to construct two independent control arrays which guide the overall solution process. As part of the control array construction, *FEAP* determines the total number of facets, number of material parameter sets, and the sets of pair data. A user need not specify the total number of pairs, facet or material sets (e.g., this is similar to *FEAP*'s ability to determine the total number of mesh nodes, elements, and element material sets in the problem). The pair data sets use the control array data sets to define and activate all *contact elements* which may then be assembled into the residual and tangent arrays during an analysis step. The use of the whole data structure is not mandatory. Consequently, a user may define contact surfaces or contact materials that are not used

within an analysis. This provides a flexibility to rapidly modify the characteristics of contact interactions. Moreover each contact pair may be enabled or disabled by specifying a feature option, without removing any data. Finally, the treatment of the contact part of an analysis can be *deactivated* simply by setting a flag. This feature permits a very efficient check on other features of the analysis without altering any contact data.

1.1.1 Surface definition

Each surface is defined as a group of *facets*. A facet is defined within the *FEAP* system by a sequence of global node numbers. For example, in a two-dimensional analysis involving surface interactions between solid elements modeled by three-node triangular finite elements (or four-node quadrilateral finite elements) a planar facet is defined by two nodes which are sequenced to traverse a boundary such that an outward normal points *away* from the body (i.e., the body lies to the left of the facet). This involves a *counter clockwise* traversing of the boundary curve.

A user has the option to use the `FACEt` command and define each facet by a its global node numbers (generation options are provided as described later) or to define a surface segment (similar to the `BLOCk` or `BLENd` mesh commands) and let *FEAP* locate the facets which lie near the region defined by the surface segment.

As a simple example, consider the definition of a contact interaction between the indentor and the platen shown in Figure 1.1.

The *FEAP* input data for the contact part of the mesh shown in Figure 1.1 is given by:

```
FEAP * * Start of Problem
  .......
END of mesh
CONTact
  SURFace 1  ! Define first surface
    LINEar
      FACEts
        1  0  9  8
        2  0  8  7
```

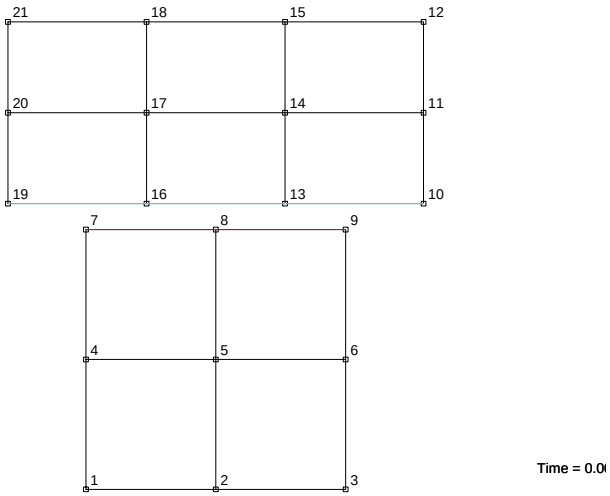

Figure 1.1: Mesh for indentor and platen for contact

```
SURFace 2  ! Define second surface
  LINEar
    FACEts
      1  0 19 16
      2  0 16 13
      3  0 13 10

PAIR 1     ! Define contact pair
  NtoS  1  2
    SOLM PENAlty  1.E+05

END contact
```

Note that in the above example no `MATE`rial parameters are specified. For the `PAIR` command a *penalty method* is requested and its parameters are associated with the *solution algorithm*, not material characteristics. On the other hand, if a frictional contact is necessary, a frictional constitutive model must be defined. For a Coulomb model where normal contacts are *rigid* the required data is:

```
MATErial 1
```

```
STANdard model
  FRICtion COULomb  0.15
```

If a penalty method also is used to impose the friction, the solution strategy record would be modified to:

```
SOLUtion PENAlty 1.E+05 1.E+04
```

where, now, the first value applies to interactions normal to surfaces and the second to tangential interactions (i.e., the frictional behavior).

The structure of the algorithm consists of a basic skeleton which can be treated as a *black box* also from the programmers view point. This skeleton governs the whole data management and the data exchange within *FEAP*. The user can program and add new subroutines for data input of particular geometry, or automatic geometry data generation. In the same way routines to read data for a user specified material model can be added, as well as the implementation of completely new contact algorithms. Data input is organized by keywords. A dictionary of keywords is defined is defined by the programmer and, in the case of new algorithms, every new keyword should be recorded within the subprogram `CONTINIT`.

1.1.2 Restrictions on input data

For the currently implemented input data forms there are some restrictions on use. These are:

1. A contact surface must be defined with facets all of the same type and number of nodes.
2. The surface element definition is strictly related to the continuum discretization.
3. A surface should pertain to only one region.
4. The same material properties are attributed to the entire surface or to the whole pair. They may be nonlinear or involve history type variables to model such phenomena as wear.

1.2 Contact input commands

All the contact commands should be placed immediately after the `END` of mesh data and any mesh manipulation data (i.e., `TIE` or `LINK` commands, and should be included within the contact start command `CONTact` and the end command `END`.

Contact data are divided into three basic parts: (a) Definition of surfaces; (b) Definition of contact constitutive laws; and (c) Definition of contact pairs. There is complete independence of the data between the contact surfaces and the contact material sets. The coupling is carried out by a proper set of input data for the PAIR command.

The following is a second example of data file:

```
FEAP * * example input file
 ......
 mesh data
 ......
END
CONT
  SURF  123  First surface
    LINE 2
    FACE
     1  1    1   2
     10 0  100 101

  SURF  27  Second surface
    LINE 2
    FACE
     1  1  700 701
     10 0  710 711
     BLOC SEGMENT
      1  0. 0.
      2 10. 2.
      3  5. 0.5

    FACE
      1  1  711 712
```

```
      10 0  718 719

  MATE  8  Simple Coulomb friction
    STAN
      FRIC COUL 0.15

  PAIR  5  First contact pair
    NTOS  27  123
      SOLM PENA 1.E5 1.E4
      MATE, , 8

END
```

In the preceding example indentation has been used to clarify interdependence between data sets.

1.2.1 Command structure

All contact commands have a standard structure:

```
CONT,string,#,#
  COMMAND, #, Comment label
    type,  #1, ....., #15
    type data (optional)}
       ! blank record closes type data if they exist
      feature, option, #1, ....., #14
      feature, option, #1, ....., #14
      feature, option, #1, ....., #14
      sub-command, option, #1, ....., #14
        subcommand data
        subcommand data (optional)
         ! blank record closes subcommand data and command

  COMMAND, #, Comment label
    ......
    ......
  END
```

Every command set is terminated one or more blank records. A single blank record also terminates input for a type and/or sub-command data set. Notice that there is no need to duplicate the blank record which closes the last subcommand of a command. All the commands have a fixed input structure, which identifies the associated data set (i.e., Surface 100 Comment; Material 1 Comment; Pair 11 Comment). It is not necessary to adopt a progressive numbering of surfaces, materials or pair sets, numbering does not affect memory allocation, which is based only on the number of commands input. This implies that one can define a problem with two contact surfaces whose numbers are 100 and 500, and then define a contact pair with number 123 that uses these surface numbers. Internally, *FEAP* will define a sequential numbering and assign tag number 100 to the first set and tag number 500 to the second (assuming they are input in this order).

The `CONT` main command has an option string and two numeric data values which are not used for normal purposes, but are very useful in debugging. The command

```
CONTact OFF
```

causes all contact data to be skipped. This option is useful for a preliminary checks on mesh data without contact. It permits the user to avoid deleting the contact data when the example is tested without contact.[1]

Use of

```
CONTact DEBUg #1  #2
```

causes contact to execute in a *debug* mode. Special debug routines perform output of various arrays and each contact routine write its name on a file each time they are called. The two related numbers define respectively the file unit for list of *call* outputs and for array outputs, respectively. Default unit numbers are 99 and 98. Output is found in files named `Cdebug` (unit #1) and `Cdebug0` (unit #2).

Use of

```
CONTact ON
```

[1] Another option is to place a `!` before the `CONTact` command.

results in normal execution mode (default mode when the option `ON` is not specified).

The currently available *contact commands* are the following:

Name	Description
SURF	Input of contact geometry
MATE	Input of contact materials
PAIR	Definition of the contact pairs
READ	Switch input to another file
SAVE	Save data on a file
END	End of contact data input

The structure of each contact command record is:

```
COMMAND # Comment_label
```

where `#` is a description number, and any comment label is simply placed in the output file.

Command data sets should terminate with a blank record. Each command can contain one or more additional data records. The first record after a command is a *type declaration*, which has the following structure:

```
type  #1 #2 ..... #15
```

Such type declarations describe the main qualifying characteristic for each command, (i.e. the type of element used for the `SURF` command, the type of material used for the `MATE` command, the type of contact formulation for the `PAIR` command.

In particular, the type declaration of the `MATE` command permits one to define the subprogram to read material data, and the type declaration of the pair command permits one to describe the corresponding contact element. A type declaration does not have a second string description and accepts a maximum of 15 numerical input values. Each specified string description is converted in a numerical value which corresponds to the position within the control array. The values of all numerical parameters input are stored in the *type* column of the command control table (see section on control tables below). A type declaration can be followed by additional

data records. This data is input by user subroutines, hence the format may vary in each instance depending on how much is input; however a standard format consisting in two strings and up to 14 numerical data is strongly recommended. Such data are stored in suitably allocated arrays, e.g., the material vector. This is the case for the material data record `FRIC COUL 0.15` in the previous example where the value of the friction coefficient must be stored as a material parameter (i.e., there are 50 values possible for each material set in the `CM` array).

A *feature record* contain information that characterizes basic choices in more detail than a *type* declaration. A feature data permits one to specify certain options available within the same contact element, e.g., the solution method using penalty or Lagrangian multipliers. The structure of a feature record is the following:

```
FEATURE, option, #1, #2, ...., ...., #14
```

Which means every feature has a string variable which describes an option of the feature, and up to 14 numerical values. Also in this case a numerical translation of the feature and option string is performed, and the data stored in a *feature* column of the command control table (see section on control tables). The number of the column correspond to the number of the feature within the control table (These are set by the order given in the subprogram `CONTINIT`).

Finally a *sub-command* declaration can be used to input and store data in the same way that the *type* declaration does.

Subcommand data is terminated by a blank record. Contact surface input can be performed by using subcommands such as: `FACEt`, `BLOCk`and/or `BLENd`. `FACEt` is a subcommand which has no options and no numeric variables on the same records. It causes input of the subsequent data records (i.e., nodal connections for each element). `BLOCk` and `BLENd` are a sub-commands which generate automatically nodal connections along an edge whose characteristics are declared in subsequent data records.

Sub-command dependent data records are read in user subroutines hence the input format has no restrictions; however, in this case also we strongly suggest to keep the feature data structure, i.e., two string data items and up to 14 numeric data items.

A programmer has the possibility to list in the database new type declarations, new features and feature options, new sub-command and sub-commands options.

A programmer also has also the possibility to add routines to input type declaration and sub-command data. Basic modifications proceed by making appropriate modifications to the subprogram `CONTINIT`.

However the current capability to input surface geometry can manage with most practical cases. Instead, it is more relevant for programmers to add new material input/computation routines.

SURFace descriptions

The `SURF` command record has the following type declarations listed:

```
TYPE,element type, # of nodes per element
```

Options available are shown in Table 1.1 and described as:

1. LINE - Two-dimensional contact element defined on the $x - y$ plane. The number of nodes (two or more) should be specified by the user.
2. TRIA - Three-dimensional triangular contact element with three or more nodes.
3. QUAD - Three-dimensional quadrilateral contact element with four or more nodes.
4. BEAM - Beam contact element with two or more nodes.
5. POIN - Point (nodal) contact element with one node.
6. RIGI - Rigid contact surface with functional form.

Note that the availability of the input routines for the various geometries does not imply the existence of any contact driver to solve a problem (In particular no use of the beam type is available). These options are simply provided to the user to input data in a standard manner and to build the control arrays. We emphasize again that construction of control tables does not imply one will use it! All the input commands simply generate and arrange the data in a suitable way for developing the compute

Option Number	Commands 1 SURF	2 MATE	3 PAIR
1	LINE	STAN	NTOS
2	TRIA	NLFR	PTOP
3	QUAD	USER	NTON
4	BEAM		PTOR
5	POIN		NTOR
6	RIGI		TIED
			CEL1
			to
			CE20

Table 1.1: COMMAND Options

capability. The possibility to solve a specific problem is checked by verifying what the available contact drivers (i.e., the subprograms `CELMT01` to `CELMT20`) can do.

No features are actually listed for the `SURF` command, instead it has the above cited sub-commands (i.e., `FACE` `BLOC` and `BLEN`), as well as, any additional ones listed in the *FEAP* user manual. Table 1.2 summarizes the available subcommand *options* for each of the surface input sub-commands.

Option Number	Subcommands 1 FACE	2 BLOC	3 BLEN	4 REGI	5 FUNC
1		GAP	GAP		CYLI
2		SEGM	SEGM		SPHE
3		POLA	EXTE		CART
4		CART			PLAN
5		REGI			POLY

Table 1.2: Surface SUB-COMMANDS Options

The `FACE` subcommand performs input of data as the standard `ELEM` command in *mesh*; however, there is no material or region associated for the contact case. If an increment different from zero is specified automatic generation of the missing

elements between the current and the next one is performed. Such generation is based on the node number of the first element and on the specified increment. Node numbers of the next element are not involved. The element input these as follows:

```
FACEt
  El.#, increment, N1, N2, ...., NN
  El.#, increment, N1, N2, ...., NN
```

The BLOC and BLEN commands perform generation of contact element for two dimensional elements of LINE type and three dimensional elements of QUAD type. The BLOC sub-command requires the following data records:

```
#_Block_Node x y z
```

whereas the BLEN command requires a sequence of *super nodes* to describe the surface to be searched. The form of the data is given as

```
S_node_1 S_node_2 .....
```

MATErial descriptions

The MATErial command is used to input contact surface material characteristics. It should be recalled that for simple contact without friction the satisfaction of the non-penetration conditions can be performed *without* any material command defined. In this case contact is treated as a purely geometrical constraint (frictionless contact). In case of frictional contacts the material friction coefficient must be specified as a material parameter. We note that in the case of a penalty method one more parameter is necessary, (i.e., the penalty value). Due to the fact that this is not a material value, but a solution strategy value, it is specified as parameter in the a feature record of the PAIR command. The MATE commands should be followed by the TYPE record. The type declaration has the following structure

```
material_type #_of_surface
```

where the #_of_surface field take value 1 if the material model is specific to one surface, or 2 if the material model takes into account the characteristics of both the contacting surfaces.

MATEerial types available are:

1. STAN - Standard rigid-with-friction material. Material data are specified in following feature-dependent data records. For the material currently available only a Coulomb friction model is available.

```
FRIC,COUL, friction coefficient
```

2. NLFR - Nonlinear friction model.
3. USER - User specified model.

It should be noted that the choice to place the input for the friction coefficient on a separate record, declaring the friction model COUL, will permit one to easily add different friction models later.

PAIR descriptions

The PAIR command collects information from the SURF and MATE data to complete the data for each contact problem. Moreover some features that pertain to the solution strategy to be employed are specified. All options have a default value, except the solution method (SOLM), which requires specification of the method and any values needed (e.g., PENA and the value of the penalty parameters). The available features and options are the following:

1. DETA: Detection algorithm to check contact status
2. MATE: Mechanical Properties to be used for contact stiffness
3. SOLM: Solution method
4. AUGM: Augmentation
5. SWIT: Activate / deactivate a contact stiffness
6. TOLE: Specify contact tolerances

The available options for the cited features are given in Table 1.3. It has to be restated that the availability of the listed features does not imply the existence of any contact driver which uses all of them. It is the programmers responsibility to develop specific contact drivers which use specific combinations of the above features.

	Features						
Option Number	1 SWIT	2 SOLM	3 DETA	4 MATE	5 AUGM	6 TOLE	7 ADHE
1	OFF	PENA	BASI		OFF	NONE	INFI
2	ON	LAGM	SEMI		BASI	PENE	STRE
3	TIMF	CROC	RIGI		HSET	OPEN	
4		CONS			LISE	OUTS	
5		SHAK			SMAU		
6		RATT					

Table 1.3: Contact pair FEATURE options

Other command descriptions

All other commands `READ, SAVE, END` are executed by calling existing subroutine of the `MESH` section, hence they are properly described in the *FEAP* Manual.

1.3 Description of subprogram structure

The contact algorithm structure is modular. The *FEAP* system connections to data are limited only to a contact switch(`CSW`). All the connections are performed by calling the same routine with a proper value of the switch. The main routine then performs a set of calls to a contact driver routine or to other *FEAP* subprograms in order to satisfy the input request. In case of data exchange with the rest of the program the contact driver routine retrieves the necessary arrays. There is no direct data exchange through the parameters of the call. Some data is exchanged by accessing *FEAP* common blocks. The main contact driver routine is called each time the element library is called. For a solution step there are two calls: (a) One just before the finite element array (residual and tangent) computations; and (b) the second just after. These entries are characterized by the contact switch `CSW` value which takes a value equal to the continuum element switch `ISW` for the second call (i.e., after the call to the finite element library), and the same value as `ISW` plus 100 (i.e., `CSW = ISW + 100`) for calls just before the finite element library call. Moreover there are direct and special calls identified by the switch values `CSW` = 200-299, 300-399, 400-499. Tables 1.4 and 1.5 show all currently defined values, and

the correspondent action performed.

The following list provides a brief description of the contact subroutines.

1. Data input - `CSW=1`

   (a) `SKIPCONT` Skip contact input data if contact is non active.

   (b) `CONTINIT` Initialize input dictionary for commands, type definitions, features, feature options, sub-commands, sub-command options, set dimensions of command control tables.

   (c) `PNUMC` Determine the number of surfaces,materials and pairs.

   (d) `COMCONTAB` Set up dimensions of contact command control tables and the length of the array requested to store them.

   (e) `PALLOC` Allocate memory for command control tables (`CO`). Allocate memory for the material data vector (`CM`). Allocate memory for the nodal connections data (`ICS`). At this stage the number of nodes to be stored is not known.

   (f) `PCONT` Main driver routine of the input phase. All the input commands are filtered here.

   (g) *PALLOC* Extend memory area for nodal connection vector, allocate memory for the history variable management correspondence array (`HIC`).

   (h) `DEFAULTP` Set default of all non explicitly declared options for the contact pair.

   (i) `CONTLIB` Switch to the requested contact element to perform the initialization phase.

   (j) `STOHMAN` Store history management correspondence vector.

   (k) *PALLOC* Allocate memory for the contact history variables (vector CH). This vector is then fragmented in three vectors, `CH1`, `CH2`, `CH3`, which correspond to the continuum element vectors `H1`, `H2` and `H3`, respectively.

The listed subroutines call the following second, third and fourth level routines:

The following call structure is the simplest one, because it requires a direct call to the contact driver with the appropriate contact switch value. The contact

CSW	A	CCW	A	CSW	A	ACTION
0	-	100	-	200	x	Show element information
1	x	101	-			Input of data
2	x	102	-			Check of data
3	2	103	x			Form stiffness / check geometry
4	-	104	-	204	2	Print contact status
5	-	105	-			
6		106				
7		107	-			
8		108				
9		109				
10		110				
11		111				
12		112				
13		113				
14	2	114	-			Initialize history variables
15		115				
16		116				
17		117				
18		118				
19		119				
20		120				
300	2					Profile maximization (obsolete)
301	x					Time step update
302	x					Back-up to the beginning of the step
403	x					Reset profile for active contacts

Table 1.4: Contact call actions based on `CSW` values

driver (user developed) can then perform the requested action locally or can call other routines (see also the description of the node-to-segment contact driver). This structure is used to satisfy request for data check (CSW=2); Compute stiffness and residuum (CSW=3); Initialize data at the start (CSW=14); print contact status (CSW=204); profile maximization (CSW=300).

1. For the values: `CSW=2, 3, 14, 204, 300` The listed subroutines call the following second level routines:
   (a) `CDRIVLIB` Contact driver library.
      i. `SETCOMP` Load on commons contact pair data for the current pair
      ii. `CDRIV#` Contact driver required by the problem described in the PAIR features
   (b) The following call structure is used to check active contact and, compute geometrical variables and determine the new shape of the stiffness matrix.
      i. For `CSW=103`:
         A. `CDRIVLIB` Contact driver library for geometry check
         B. `RSTPRF` Reset profile for continuum discretization

`CSW` Values	Description
`0<=CSW<=20`	Call from FORMFE after continuum elements to perform an equivalent action
`100<=CSW<=120`	Call from FORMFE before continuum element call to perform special action
`200<=CSW`	Direct call outside FORMFE to perform an equivalent action
`300<=CSW`	Call for element non–standard calls
`400<=CSW`	Special internal calls
x	Action performed in a proper section
`#`	Action performed in section `#`
-	Not allowed —return with no warning
	Action still not defined—return with no warning
I	Internal call not from CONTLIB

Table 1.5: Contact call actions based on `CSW` values

Subprogram	Description
SKIPCDAT	Skip input data between contact commands.
CRSURF	Driver to read and print surfaces data.
CRMATE	Driver to read and print material data.
CRPAIR	Driver to read and print pair data.
READFL	Switch input data reading to another file.
SAVEFL	Save data on a file.
CUNU1	Unused contact command # 1.
CUNU2	Unused contact command # 2.
CUNU3	Unused contact command # 3.
CRTYPE	Input subroutine for reading type declarations.
CRDATA	Input subroutine to read features and sub-commands.
CREL01	Read surface element connections generated by the FACE sub-command
CREL02	Read surface element connections generated by the BLOC sub-command
CRBLOK	Perform automatic generation of the BLOC command
CRMAT01	Read material data requested by the type declaration, for simple no-material with Coulomb friction
CRMAT02	Unused subroutine available for a new material
CUMATER	Unused subroutine available for a new material
CRSURF	Unused routine to read type declaration data or sub-command data.
SETCOMP	Load on commons contact pair data for the current pair
CELMT#	Contact driver routine. Equivalent to the standard element routine ELMT#
ACTIVE	Function that performs variable activation and definition of the number of sets required for the pair.

C. CDRIVLIB Internal call (CSW=403) to reset profile for contact

D. NWPROF Set new pointers for the profile

(c) The following structure is used to show element information. In this case all the available element are scanned to check their properties.

i. For: CSW=200

A. CDRIVLIB Contact driver library for geometry check

B. `RSTPRF` Reset profile for continuum discretization

Also in this case the listed subroutines call the same second level routines of the previous case.

(d) The next structure is called to perform time step updates

i. For `CSW=301`

A. `CRESHIS` Perform dump of the history vector `CH2` on to `CH1`

No higher level subroutines are called.

(e) The next structure is called to perform time step update

i. For `CSW=302`

A. `CRESHIS` Perform copy back of the history vector `CH1` on to `CH2`.

No higher level subroutines are called.

All the other still undefined or not allowed entries are processed in silent mode.

1.3.1 Sizing of arrays

The limits on storage of various data arrays in the contact elements is set in the include file `C_0.H`. The file is given as

```
                          ! CONTACT PARAMETERS

integer    c_ncc,c_ncs,c_ncel,c_lp1,c_lp3,c_lmv

parameter (c_ncc=10)     ! # available contact commands
parameter (c_ncs=200)    ! # available command strings
parameter (c_ncel=22)    ! # available contact elements
parameter (c_lp1 = 200)  ! # available history variables
                         !   for vectors CH1 & CH2
parameter (c_lp3 = 100)  ! # available history variables
                         !   for vectors CH3
parameter (c_lmv = 50)   ! # available material parameters
```

Generally, this file must be included in any file which contains contact common files (i.e., any include file which has name `C_xxxx.H`.

1.3.2 Contact command control table

For each contact command used in the input file a control table is built up. Such table permits to store all the options associated to the command. It permits also to deposit memory offsets or other values specifically related to the command itself. In case some options are not specified in input, default values are assigned.

This control table is a matrix here all the descriptions for input or default data are stored. All the control tables have the same number of rows, currently set to 16. This corresponds to the maximum number of variables which may be assigned to data record. The number of columns depends on the number of *features* defined for the command, plus the number of *user* defined columns, plus the number of *system* defined columns, plus a *type* declaration column. The number of rows is the same for all the table, and the size of each control table is hence defined by:

1. **Feature columns**: There is one columns for each assigned feature. The number of features is assigned in subprogram `CONTINIT`.
2. **User extra columns**: These columns are available for the user to store user values related to that specific command. The number of user extra-columns should be set in the initialization routine CONTINIT, the default value is zero.
3. **System extra columns**: These columns are used by the contact skeleton to store pointers or other global values. They have been set for each table and should not be changed. Generally, the system columns are assigned to negative column indices in each control table and are not passed to the contact driver routine.
4. **Type declaration column**: This column is similar to the feature columns, and stores the type data. This data is assigned to column zero in each table.

All the values which define the size of each control table are grouped in the subroutine `CONTINIT`, and can be easily modified.

The number of control tables depends on the number of commands input to describe the contact problem. One pair control table is defined for each command `PAIR` appearing in the input data and one surface control table is constructed for each `SURFace` command appearing. All control tables are assigned to the array `C0` allocated by the subprogram `PALLOC`. Tables are stored by contact command order, and then tables related to the same commands are sorted by number.

Command Number	System -1	Type 0
1	Pair No.	ELMT No.
2	$h1_{offset}$	S_1
3	$h3_{offset}$	S_2
4	l_{h1}	-
5	l_{h3}	
6	nset	
7	nsurf1	
8	nsurf2	
9	nmat1	
10	nmat2	
11	nacte	
12	genf	
13	ncdim	

Table 1.6: Program set contact pair control array - `CPO`

Command Number	Features							User
	1	2	3	4	5	6	7	8
1	SWIT	SOLM	DETA	MATE	AUGM	TOLE	ADHE	-
2	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	Opt.	-
3	Norm.	K_n	-	M_1	-	tlpen	σ_{ad}	-
4	Tang.	K_t		M_2		tlopn	-	
5	Ther.	K_h		-		tlout		
6	-	-				-		

Table 1.7: User set contact pair control array - `CPO`

Option Number	Features								
	-1	0	1	2	3	4	5	6	7
1	npair	ndrv							
2	ofh1			ifsolm	ifdeta		ifaugm		ifadhe
3	ofh3		ifon					tlipen	
4	lh1		iffric					tlopen	
5	lh3							tlouts	
6	nset								
7	nsurf1								
8	nsurf2								
9	nmat1								
10	nmat2								
11	nacte								
12									
13	cndm								

Table 1.8: Variable names set in contact pair table

System -1	Type 0	Feature 1	User 2
No. Surf.	TYPE	-	-
s_{offset}	nope		
e_{max}	-		
dnope			
-			

Table 1.9: Contact surface control array - `CS0`

Chapter 2

Contact driver: The CELMTnn subprogram

All the connection with the *FEAP* program takes place through the main contact subroutine `CONTACT`. The subroutine receives only the contact switch value for `CSW`, and then performs the requested activity switching to the input routines, or to the contact elements library routine `CONTLIB` which calls the appropriate contact driver routine (e.g., a routine between `CELMT01` and `CELMT20`). A typical structure for a contact driver routine is given by:

```
      subroutine celmt01 (ndm,ndf,x,u,
     &    csw,npair,cs01,cs02,cm01,cm02,cp0,
     &    ix1,ix2,cm1,cm2,ch1,ch2,ch3,ww1,ww3)
c-----[--.----+----.----+----.----+----.----+----.----+----.----]
c      Inputs :
c         ndm     - Space dimension of mesh
c         ndf     - Number dof/node
c         x(*)    - Nodal coordinates
c         u(*)    - Current nodal solution vectors
c         csw     - Contact switch
c         npair   - # of current pair
c         cs01(*) - Contact surface  control data for surface 1
c         cs02(*) - Contact surface  control data for surface 2
c         cm01(*) - Contact material control data for surface 1
```

```
c         cm02(*) - Contact material control data for surface 2
c         cp0(*)  - Contact pair control data
c         ix1(*)  - Element nodal connection list for surface 1
c         ix2(*)  - Element nodal connection list for surface 2
c         cm1(*)  - Contact materials data storage for surface 1
c         cm2(*)  - Contact materials data storage for surface 2
c      Outputs:
c         ch1(*)  - Contact history variables (old)
c         ch2(*)  - Contact history variables (current)
c         ch3(*)  - Contact history variables (static)
c         ww1(*)  - Dictionary of variables for CH1 & CH2
c         ww3(*)  - Dictionary of variables for CH3
c-----[--.----+----.----+----.----+----.----+----.----+----.----]
      implicit  none

      include  'c_0.h'   ,'c_comnd.h','c_contac.h','c_geom.h',
      include  'c_keyh.h','c_mate.h','c_pair.h','c_tole.h'
      include  'iofile.h','print.h'

      character ww1(*)*(*),ww3(*)*(*)
      integer   ndm,ndf,csw,npair,ix1(dnope1,*),ix2(dnope2,*)
      real*8    cs01(nr0,n0c1:*),cs02(nr0,n0c1:*),cm01(nr0,n0c2:*)
      real*8    cm02(nr0,n0c2:*), cp0(nr0,n0c3:*),cm1(*),cm2(*)
      real*8    ch1(lh1,*),ch2(lh1,*),ch3(lh3,*),x(ndm,*),u(ndf,*)

      call cdebug0 ('    celmt01',csw)  ! Outputs debug data

      if     ((csw.eq.  1) then ! Initialize assign history
      elseif ((csw.eq.  3) then ! Compute tangent and residual
      elseif ((csw.eq.103) then ! Compute contact geometry
      elseif ((csw.eq. 14) then ! Initialize history data
      elseif ((csw.eq.400) then ! Start new problem
        once = .true.
      endif

      end
```

The first few arguments in the driver subprogram `CELMTnn` are values associ-

ated with the finite element model. Thus, NDM and NDF are the space dimension of the mesh and the (maximum) number of degrees of freedom associated with each node, respectively; X is the array of nodal coordinates (type REAL*8) dimensioned X(NDM,*); and U is the array of solution parameters (REAL*8) dimensioned U(NDF,*) (actually the array is dimensioned U(NDF,NNEQ,3) where the second and third columns contain incremental values; however, the geometric aspects of contact normally require only the solution parameters to construct current coordinates). Using these two arrays, the current position of a node NN may be computed as

```
DO I = 1,NDM
  x_cur(I) = X(I,NN) + U(I,NN)
END DO ! I
```

where it is assumed that $u_i,\ i = 1, ndm$ contains displacements in the direction of x_i.

The next two arguments on CELMTnn are the contact switch parameter CSW and the pair number being processed, NPAIR, both are of type INTEGER. The NPAIR parameter is used only for output and thus is not usually needed during any computation phase.

2.1 Control data tables

The arguments CS01 and CS02 provide the values in the surface control data tables for surface number 1 (the first surface number on the PAIR command) and surface number 2 (the second surface number on the PAIR command, respectively. These tables are dimensioned

```
REAL*8    CS01(NR0,N0C1:*),CS02(NR0,N0C1:*)
```

The number of rows in each array is NR0 and is currently set to 16. The column numbers define the feature and user columns and N0C1 is currently set to 1. Based on the problem input records the data in these arrays is assigned as described in Tables 1.2 and 1.9.

Similarly, the material control data is passed through arguments CM01 and CM02. These are dimensioned

```
REAL*8     CM01(NR0,N0C2:*),CM02(NR0,N0C2:*)
```

These also describe the feature and user data starting with N0C2 (currently set to 1).

Finally, the pair control data is passed as the argument CP0 and is dimensioned

```
REAL*8     CP0(NR0,N0C3:*)
```

in which N0C3 is set to 1. The data is stored as described in Tables 1.3, 1.6 and 1.7.

2.2 Pair data: Surface arrays

The nodal connection lists for surface 1 and surface 2 are passed through the arguments IX1 and IX2, respectively. These are dimensioned

```
INTEGER    IX1(DNOPE1,*),IX2(DNOPE2,*)
```

in which DNOPE1 and DNOPE2 are defined in common block C_GEOM as described in Table 2.3. The actual number of nodes attached to each connection array may differ from the dimension and are given by the parameters NOPE1 and NOPE2, also passed through common C_GEOM. The main difference is for the LINE option where there are two added columns to assist locating the geometric point of contact. A typical array (e.g., IX1) then has the form

NODE_1	NODE_2	ELMT_1	ELMT_2
IX1(1,*)	IX1(2,*)	IX1(3,*)	IX1(4,*)

in which NODE_1 and NODE_2 are the facet global node numbers and ELMT_1 is the facet number adjacent to the current facet (before) and ELMT_2 is the facet number which is adjacent (after). A zero ELMT_1 or ELMT_2 define the ends of the surface (note there can be only one ELMT_1 and one ELMT_2 defining end points on any one surface – i.e., the surface must be connected). Using this scheme it is easy to locate an adjacent element when the contact node slides from one facet to an adjacent one.

```
c     Locate start segment

      do nel1 = 1, neps1
        if(ix1(dnope1-1,nel1).eq.0) then
          ns1 = nel1
          go to 100
        endif
      end do ! nel1
 100  continue

c     Loop over segments (Forward sequence)

      check1 = .true.
      do while (check1)
        ixl(1) = ix1(1,ns1)
           ... Insert rest of code
        ns1 = ix1(dnope1,ns1)
        if(ns1.le.0) then
          check1 = .false.
        endif
      end do ! while check1
```

Figure 2.1: Sequential search for `LINE` surface

A simple example for a search which starts at the first segment and continues to the last is given in the code fragment of Fig. 2.1.

When matching with another surface to find a possible contact pair one may wish to traverse in a reverse sequence. A code fragment for this is given in Fig. 2.2.

Other command options than `LINE` do not have additional columns (thus, `DNOPE1 = NOPE1`), and thus, all columns denote potential contact node numbers.

The geometry of the facets described by the surface node connection numbers in arrays `IX1` and `IX2` are used to find which parts of surface pairs are in contact and which are not. Thus, when `CSW = 103` it is necessary to check all the facets on surface `IX1` against those on surface `IX2` and determine, using whatever contact strategy is being considered, whether a *contact state* exists or not. This aspect is quite

```
c     Locate start segment

      do nel2 = 1, neps2
        if(ix2(dnope2,nel2).eq.0) then
          ns2 = nel2
          go to 200
        endif
      end do ! nel2
 200  no2 = ns2

c     Loop over segments (Reverse order)

      ns2     =  no2 ! Can use to restart at 'no2'
      check2  = .true.
      do while (check2)
        ixl(...) = ix2(1,ns2)
           ... Insert rest of code
        ns2 = ix2(dnope2-1,ns2)
        if(ns2.le.0) then
          check2 = .false.
        endif
      end do ! while check2
```

Figure 2.2: Reverse search for LINE surface

different from coding of standard finite elements for *FEAP* and why it is necessary to have a special module to carry out contact. Currently implement algorithms use either a node to node algorithm (NtoN or PtoP option on the PAIR command) or a node to surface algorithm (NtoS option on the PAIR command. Thus, for any other strategy it is necessary for users to construct their own module (i.e., the contact driver routine CELMTnn). Indeed, users may find better strategies for even the node to node or node to surface algorithms currently in the program.

2.3 Material data

For material models which have parameters to describe their behavior the contact driver passes the arrays CM1 and CM2 for the surface pairs 1 and 2, respectively. These arrays are dimensioned

```
REAL*8     CM1(*),CM2(*)
```

and, thus, it is evident they apply to all facet pairs of the current contact surfaces.

2.4 History data management and assignment

The arrays which contain any history data are passed through the arguments CH1 (for data defined at t_n), CH2 (for data described at t_{n+1}) and CH3 for data independent of time. In addition two character arrays W1 and W3 are passed to facilitate the assignment of specific data items to each of the history arrays. The W1 and W2 arrays are dimensioned as

```
CHARACTER W1(*)*(*),W3(*)*(*)
```

To understand how the CHi data is used, it is necessary to describe in more detail the method used within the contact module to manage this data.

To manage the assignment of the history data depending on what data in actually input, two routines are written which describe all the types of history variables possible and those which are actually active. One subprogram is the define routine and the other the activate routine which will look at the data and make appropriate choices. A typical *definition routine*, called DEFHV01 here, is given in Table 2.1.

During contact definition (generally when CSW = 1 the necessary parameters to perform a contact analysis are activated using a set of calls to ACTIVE. These may be placed in an *activation routine*, called ACTHV01 here, as shown in Table 2.2. With this structure it is possible to have just the number of history variables needed to solve each specific problem. There are a number of parameters which are set automatically depending on the contact data provided as input. A list of these parameters is given in Table 2.3.

```
      subroutine defhv01 (ww1,ww3)
c-----[--.----+----.----+----.----+----.----+----.----+----.----+----.----]
c      Outputs:
c         ww1(*)   - Dictionary of variables for CH1 & CH2
c         ww3(*)   - Dictionary of variables for CH3
c-----[--.----+----.----+----.----+----.----+----.----+----.----+----.----]
      implicit  none

      character ww1(*)*8,ww3(*)*8

      call cdebug0 ('  defhv01',0)

c     CH1 & CH2 VARIABLES (dynamic, CH2 copied in CH1)

      ww1(1) = 'masts' ! Master segment number
      ww1(2) = 'istgn' ! Contact normal   state indicator
      ww1(3) = 'istgt' ! Contact friction state indicator
      ww1(4) = 'gapn'  ! Contact normal   gap
      ww1(5) = 'gapt'  ! Contact tangential slip
      ww1(6) = 'fn'    ! Normal contact force
      ww1(7) = 'ft'    ! Tangential contact force

c     CH3 VARIABLES (static, never automatically modified)

      ww3(1) = 'area'   ! Area of contact surface

      end
```

Table 2.1: Definition of history variables

As noted above, the history variables for each contact pair are passed through the argument list of the contact driver subprogram (`CELMTnn`) as `CH1` (data at time t_n), `CH2` (data at time t_{n+1}) and `CH3` (data not changing with time). The arrays `CH1`, `CH2` and `CH3` are dimensioned in the driver as:

```
       REAL*8    CH1(LH1,*),CH2(LH1,*),CH3(LH3,*)
```

```
      subroutine acthv01 (nset)
c-----[--.----+----.----+----.----+----.----+----.----+----.----+----.----]
c      Inputs :
c         nset    - # of history set required for contact pair
c-----[--.----+----.----+----.----+----.----+----.----+----.----+----.----]
      implicit  none

      include  'c_pair.h'
      logical   errck,active
      integer   nset

      call cdebug0 ('  acthv01',0)

c     Activation of variables

      errck = active ('istgn',1)
      errck = active ('gapn' ,1)
      errck = active ('fn'   ,1)
      errck = active ('area'   ,1)

      if (iffric.eq.1) then    ! SET FOR FRICTION
        errck = active ('istgt' ,1)
        errck = active ('gapt'  ,2) ! Two components in 3-D
        errck = active ('ft'    ,2) ! Two components in 3-D
      endif

c     Stop variable activation and define # of data sets

      errck = active('stop', nset)  ! Must be last call

      end
```

Table 2.2: Activation of history variables

where LH1 is the number of variables assigned to each contact element for the CH1 and CH2 arrays (this is the number allocated by the subprogram ACTHVnn as W1(j) items) and LH3 is the same for the items named W3(j). Note that all history variables

Variable Name	Type	COMMON BLOCK	Description (Values)
iffric	Int	C_PAIR	0 = Frictionless; 1 = Friction
ifsolm	Int	C_PAIR	1 = PENA; 2 = LAGM; 3 = CROC; 4 = CONS
ifdeta	Int	C_PAIR	1 = BASI; 2 = SEMI; 3 = RIGI
ifaugm	Int	C_PAIR	0,1 = OFF; 2 = BASI; 3 = HSET; 4 = LISE; 5 = SMAU
ifadhe	Int	C_PAIR	1 = INFI; 2 = STRE
tlipen	Real	C_TOLE	Tolerance for initial penetration
tlopen	Real	C_TOLE	Tolerance for opening gap
tlouts	Real	C_TOLE	Tolerance for out of segment
neps1	Int.	C_GEOM	Number of elements on surface 1
neps2	Int.	C_GEOM	Number of elements on surface 2
dnope1	Int.	C_GEOM	Dimension for IX1 array
dnope2	Int.	C_GEOM	Dimension for IX2 array
nope1	Int.	C_GEOM	Number nodes/element on surface 1
nope2	Int.	C_GEOM	Number nodes/element on surface 2
ifsty1	Int.	C_GEOM	Surface 1 type: 1 = LINE; 2 = TRIA; 3 = QUAD; 4 = BEAM; 5 = POIN ; 6 = RIGI
ifsty2	Int.	C_GEOM	Surface 2 type: 1 = LINE; 2 = TRIA; 3 = QUAD; 4 = BEAM; 5 = POIN ; 6 = RIGI
ifmty1	Int.	C_MATE	Surface 1 material type: 1 = STAN; 2 = NLFR; 3 = USER
ifmty2	Int.	C_MATE	Surface 2 material type: 1 = STAN; 2 = NLFR; 3 = USER

Table 2.3: Parameters for use in contact driver programs

are stored as `REAL*8` values, thus, as in treatment of history variables in the finite elements, it is necessary to recast any integer values using a statement

```
II = NINT(CH1(...))
```

Specific data items are found using two *pointer* arrays named `P1(*)` for those associated with `W1(*)` assignments and `P3(*)` for that of `W3(*)`. For example, to extract

the value of the gap at time t_n for the *element* number NELM for the assignment order given in Table 2.1, one uses the statement:

```
NGAP = CH1(P1(4),NELM)
```

since the normal gap is defined by W(4). Note that it is not necessary to use the same name as given for the definition, only the same position. Similarly if one wanted to extract the area to be used for the same element one uses the statement

```
AREA = CH3(P3(1),NELM)
```

Care must be taken to ensure that the specific variable was activated for the problem at hand (i.e., checks such as given in the activation subprogram described in Table 2.2 should be included). For example to extract the friction force one should use

```
IF(IFFRIC.EQ.1) THEN
  FT = CH2(P3(7),NELM)
ELSE
  FT = 0.0d0
ENDIF
```

to ensure that correct extraction is made (of course the above may need to be modified if other friction models are described for the IFFRIC variable).

2.5 Options in driver program

Tables 2.4 to 2.6 describe all the direct calls to CELMTnn which currently exist. A user will not need to code all of the options to get a working element (see below for more information on what MUST always be implemented).

The other indirect calls to the contact elements are defined by the CSW values shown in Table 2.7

Remarks:

Calling Routine		CSW Value	Description of action to be performed in contact driver routine.
FORMFE	X	isw	Perform operation equivalent to isw in FE's Not called when 'isw' is 1 (MATE); 4 (STRE); 5 (MASS); or 7 (Obsolete surface load treatment). N.B. FORMFE is the routine which does all finite element array calculations – it always calls CONTACT (ISW).
CONTACT	X	0	Called after initialization to allow users to change default pair name 'celn' to any character name.
PCONTR	X	1	Called immediately after 'CONT'act data input. Perform any sets on 'input' parameters; must define all history variables which can ever exist. Must be processed only once, thus it requires a 'once' flag to test against. N.B. In fact, like normal input data, FEAP reads the contact data twice: Once to determine how many surfaces, pairs, materials exist (used to define the tables) and Second to store the data in the appropriate allocated arrays.
PMACR1	X	103	Determine which elements are in contact to adjust matrix storage. First pass: CSW = 103 Second pass: CSW = 403 : ICCOM = 1; NCEN = 0; NUMELC = 0. If NUMELC ¿ 0 after second pass then: Third pass: CSW = 403 : ICCOM = 2;NUMELC = 0. If optimization of profile or Lagrange multiplier then: Fourth pass: CSW = 403 : ICCOM = 3; For sparse solver another pass is required: Last pass: CSW = 403 : ICCOM = 4.
PMACR5	X	200	Called when command 'SHOW CONT' given.

Table 2.4: Existing calls to contact drivers (Part 1)

- N.B. The following values of CSW are not processed: CSW = 0, 4, 5, 7. Any others not given above let the element decide: IFCHIS = F; call sets CSW = ISW.
- Any omitions may be checked in file 'contact.f' in the /contact/main directory.
- An 'X' in the second column indicates that the contact driver will be called with the CSW set to the value indicated. If not, 'description' gives CSW the 'value' in the 'call contact (value)' indicated.

The CSW values which MUST be in the CELMTnn driver:

- CSW = 0 : Change default names 'cel1' to 'ce20' to user defined name. Inset statements below:

```
include 'umac1'
logical  pcomp
integer  typ
  ...
if(csw.eq.0) then
  if(pcomp(uct,'celn',4)) then
    uct = 'user_name' ! 4-characters
  endif
```

  where `n` is the number of the contact element (i.e., the number after `CELMT` without the zero) and `'celn'` is given as `'cel1'` to `'ce20'` depending on the `n` value.

- CSW = 1 : Set variable `once` to `.false.` (Note it can be set true at CSW = 400). Define all possible history variables (DEFHVAR).
- CSW = 14 : Initialize any non-zero history variables.
- CSW = 3 : Compute tangent and residual – must finish with call to routine CONSTASS.
- CSW = 6 : Compute residual – must finish with call to routine CONSTASS. (same for CSW = 206).

- CSW = 103 : Do search for active contact elements. For some cases it may be best to do little here and do most in 403. I think you should be able to use the statement structure in file CNTS2D.F to do the search (except for GEOPAR's). In particular, the routine GLOSCLN and MASTSEG should work for the 3-d case (Note you must then have the same values for the ww1(1), ww1(2) and ww1(3) in your DEFHVAR routine) ch.(p1(1)) is the number of the master facet for the current slave node; ch.(p1(2)) is the number of the closest local node; and ch.(p1(3)) is an indicator on what may be happening near an intersection between two facets (when the search cannot make up its mind which should be used). Generally if the output is not 1 (unity) one should use both facets and do a corner condition (I think!).

- CSW = 304 : Do search to find active contact elements. Same details as for CSW = 103 this form is used when the command sequence is

```
LOOP,check,no_ck
  CONTact CHECk                [call contact(304)]
  LOOP,newton,no_nt
    TANG,,1 (or UTAN,,1)
  NEXT,newton
NEXT,check
```

  instead of just

```
LOOP,newton,no_nt
  TANG,,1 (or UTAN,,1)         [call contact(103)]
NEXT,newton
```

  (which should check state contact each iteration) and generally leads to more robust performance.

  When the form for CSW = 304 is coded the flag `IFISTGN` (located in common `C_CONTAC.H` must be checked in the CSW = 103 portion. If it is *false* no contact search should be performed (however, the location of the contact position on the currently active master should be recomputed); if the value is *true* then the full check should be made. Careful attention to the details in coding these two values of CSW must be taken to ensure good performance overall. (As a side note, the standard features in the three types of contact elements currently in the program do not perform correctly for both algorithms.)

- CSW = 313 : Activate the history variables which INPUT says are needed (ACTHVAR).
- CSW = 403 : Set list of elements which will be active in next solution. Called when CSW = 103, but to work for all solution options (e.g., profile or sparse) the call to MODPROF must be given when CSW = 403.

Optional CSW which may be good to implement:

- 10 : Do augmented update. Check flag: IFAUGM ¿ 0. When true do augmented update on the contact force: $F_n|_a ug <-- F_n|_a ug + k_n * gap_n$ N.B. When augmenting is done one MUST check on the sign of F_n to determine when contact is made. The value of the gap_n can only be used to check if the gap is really open and no contact has ever occurred. Also, it will be necessary to monitor the gap_n to detect an initial contact (i.e., when F_n is zero the solution will run until the gap_n penetrates and then one introduces the 'penalty' solution to prevent further penetration. Once this has happened (i.e., the value of $F_n|_a ug$ will be zero) the computation of the force F_n will be done as $F_n = F_n|_a ug + k_n * gap_n$ and then check conditions on the state of contact. One does this because at convergence $gap_n -- > 0$ (and may change sign due to roundoff in computing the zero!).
- 204 : May want to output some values for history variables which can be useful for a 'user' to know. (or maybe for debugging).
- 305 : Plot of the slideline surfaces. This helps to ensure date has been input. You should be able to use the statements below:

```
elseif(csw.eq.305) then
  call c2geoplt(ix1,ix2,2,6) ! 2 = ix1 , 6 = ix2 colors
elseif(csw.eq.....
```

2.5.1 Lagrange multiplier constraints

One solution option within the `PAIR` command if `LAGM`. This option permits the imposition of constraints using a Lagrange multiplier method. For this option to function correctly, users must check the solution flag `IFSOLM`. Values of the flag for

a penalty solution are set to unity (1) and for a Lagrange multiplier method to two (2).

For a Lagrange multiplier to be properly handled users should have the following options (in addition to or modified from those above):

- In the definition of history variables provisions must be made to store the values of all the Lagrange multipliers in each element. These should be activated when IFSOLM is two (2).
- For CSW = 3: Assembly should be performed according to:

```
if    (ifsolm.eq.1) then
  call constass(ixl,ida,nnod,ndof,ilm,   0,   0,size,s,r)
elseif(ifsolm.eq.2) then
  call constass(ixl,ida,nnod,ndof,ilm,lnod,nlag,size,s,r)
endif
```

  where IXL is an array storing the NNOD nodal values which are active in the current element; IAD is an NDOF array defining the degrees of freedom to be assembled; ILM is a list of LNOD nodes to which Lagrange multipliers are associated (N.B. There is no scheme to associate them to a contact element); and NLAG is the number of multipliers at each node (all nodes are assumed to have the same number within the driver elements); SIZE is the first dimension of the tangent stiffness array S; and R is the residual vector.

  A similar assembly scheme must be included for residual calculations computed when CSW = 6 or 206.

- For CSW = 403: The program must include a call to the routines which perform calculation of the profile. These are given by:

```
if    (ifsolm.eq.1) then
  call modprof(ixl,ida,nnod,ndof)
elseif(ifsolm.eq.2) then
  call modprof(ixl,ida,nnod,ndof,ilm,lnod,nlag)
endif
```

  where the parameters are identical to those described for the call to the CONSTASS subprogram.

- For CSW = 314: Updates of the Lagrange multipliers should be performed using the following call

```
if(contact_active) then
  call getlagm(ilm,lnod,nlag,ch2(p1(.),kset))
else
  ch2(p1(.),kset) <-- zero
endif
```

  Here the CH2(p1(.),kset) are the history variables for the current time (there must be LNOD*NLAG values available. They should be set to zero whenever the element is inactive.

The actual calculations for all the operations necessary to insert the multiplier equations into the profile are carried out by the main program CONTACT and the subprograms called above. Operations performed by each user are merely the building of the node lists IXL and ILM together with their sizes.

Calling Routine		CSW Value	Description of action to be performed in contact driver routine.
PMACR3	X	203	Executed on command 'OPTI' profile. CSW = 103 First pass: CSW = 103 Second pass: CSW = 403 : ICCOM = 1; NCEN = 0; NUMELC = 0. Third pass: CSW = 403 : ICCOM = 2;NUMELC = 0.
PMACR1	X	204	Called when 'STRE,CONT' given to output any contact "stress" values.
PTIMPL	X	206	Called to set 'cpl(*)' array values for any contact time history values. Activated by 'CONT,N1,N2' after a 'TPLO't command.
PCONTR		300	Start of new problem. Program sets flags IFCT = F; IFDB = F; LAGRM = F.
AUTBAC	X	301	Set values to start a time step ('TIME') This call occurs during an auto time step. Generally not necessary to do anything.
PMACR2	X	301	Set values to start a time step ('TIME') Generally not necessary to do anything.
AUTBAC	X	302	Reset history data to start values ('BACK'). Generally not necessary to do anything.
OUTARY		303	Called to 'dump' values to screen on a 'SHOW XX: XX = C0, CH, CM, ICS, HIC'.
PMACR3	X	304	Called on 'CONT,CHEC'k or 'CONT,NOCH'eck solution command. IF 'CHEC' flag set to IFCHIST = T; if 'NOCH' set to F before call to contact element driver.
PPLTF	X	305	Called on: PLOT,PAIR,k1,k2,k3 command.
RESTRT		306	Called on 'REST'art solution command after all data has been read.
RESTRT		307	Called on 'SAVE' solution command after all data has been written.
PPLTF	X	308	Called on: PLOT,CVAR,k1,k2,k3 command. First pass: CSW = 308: Determine min/max. Second pass CSW = 408. Do plot.

Table 2.5: Existing calls to contact drivers (Part 2)

Calling Routine		CSW Value	Description of action to be performed in contact driver routine.
PMACR3		309	Called on 'CONT,ON' or 'CONT,OFF' solution command. For 'ON' set flag IFCT = T; if 'OFF' set flag F.
PMACR3	X	310	Called on 'CONT,PENA' or 'CONT,FRIC' solution command. Command is: CONT XXXX N1 V1 V2. IF XXXX = PENA, N1 is pair number, CVALUE(1) = V1; CVALUE(2) = V2. IF XXXX = FRIC: Flags set: IFFRON = T; and IFCHIST = F. IF XXXX = NOFR: Flags set: IFFRON = F; and IFCHIST = F.
PCONTR		312	Called after a 'TIE' to reset any eliminated node numbers on the contact facet data.
PCONTR	X	313	Called to ACTIVATE history variables. Users define all active history variables. First pass: CSW = 313: Use ACTHVAR routine. Second pass: CSW = 400: Set 'once' true.
UPDATE	X	314	Perform any updates on history data. Called after a 'SOLV', 'TANG,,1' or 'UTAN',,1. Use for updates on any contact solution variables. For example, Lagrange multipliers.

Table 2.6: Existing calls to contact drivers (Part 3)

Calling Routine		CSW Value	Description of action to be performed in contact driver routine.
	X	400	From CSW = 313. Used to avoid mult calls.
	X	403	From CSW = 103. Users to determine active equations and make a call to 'modprof' or 'modprofl'
		408	From CSW = 308. Do actual plotting for hist variables.

Table 2.7: Indirect calls to contact drivers

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