8 OUTPUT

The results of USFOS analyses are

- Ultimate collapse load or critical collapse temperature
- Energy absorption
- Load displacement relations at any nodal point
- Element forces at all load levels
- Formation of plastic hinges
- Redistribution of forces

The results may be studied directly from the Analysis Print File, or by running the postprocessing module POSTFOS. In addition, selected data are written directly to terminal or batch-out stream.

All results tables, plots and figures of this section are results from USFOS analysis of the test frame presented in Section 11.3 /7/.

8.1 OUTPUT TO ANALYSIS PRINT FILE

The Analysis Print file is a symbolic file generated during USFOS nonlinear analysis. The file contains input verification data and analysis results at each load step.

The amount of print is controlled by the user through the parameters *inprint* and *outprint* governing input verification print and analysis output, respectively (Section 6.3.B).

8.1.1 Analysis Identification

The program identification and analysis heading (Section 6.3.A) are written to the top of the file, with data and time of analysis.

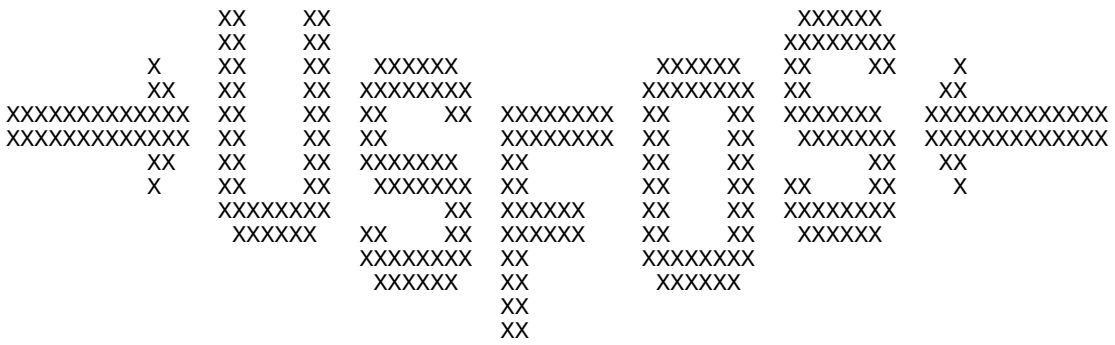


Figure 8.1 Print file heading

8.1.2 Input Verification

The amount of input verification data is governed by the input parameter *inprint* (Section 6.3.B).

The minimum amount of print is shown in Figure 8.2. This is key-parameters, load control data, displacement control data and element imperfection data (if any).

Additional input verification data is

- Structural Data
  - Nodal point data
  - Element data
  - Local coordinate system data
  - Material data
  - Spring characteristics
  - Cross sectional data

- Load Data
  - Nodal point loads
  - Distributed element loads
  - Gravity loads

- Internal F.E.M parameters
  - Nodal degrees of freedom
  - Element degrees of freedom
  - Nodal point connectivity

An example of structural data is shown in Figure 8.3.

```
======   A N A L Y S I S    P A R A M E T E R S   ======


                    Z A Y A s  FRAME
              U S F O S  progressive collapse analysis
            S I N T E F  div  of  Structural  Engineering

           Number of input lines read             =  220

           Number of nodal points                 =   13
           Number of structural elements          =   23
           Number of springs to ground            =    0
           Number of shell property elements      =    0
           Number of overlaps                     =    0
           Number of damaged elements             =    0
           Number of materials                    =    3
           Number of cross sections               =    5
           Number of spring characteristics       =    0
           Number of linear dependencies          =    0
           Number of element imperfection groups  =    0
           Number of local element coord. systems =   23
           Number of local nodal coord. systems   =    0
           Number of eccentricity vectors         =    0
           Number of load cases                   =    1
           Number of temperature fields           =    0
           Number of load combinations            =    0
           Number of control nodes                =    1
           Number of steps in post-collapse       =   15

           Numerical accuracy equation solver     =  1.00E-20
           Numerical accuracy interaction surface =  1.00E-01

           Combined shape function,   load level  =   .050
           Max recalculations due to unloading    =    5
           Elastic spring-back introduced at CSTF >  1.20E+00
           Local dent formulation used
           Restart data stored at intervals       =   1


------    L O A D    C O N T R O L    D A T A     ------

           USFOS    Load      Max.     Max.     Min.
           load    scaling    load    no. of   displ.
           comb.    factor    level    steps    step

             1      1.000     5.000      0      .010
             1       .500     6.500      0      .010
             1       .050      .000     20      .005
             1       .100     8.000     40      .010


------    D I S P L A C E M E N T    C O N T R O L    ------

             External     Global     Displacement
              node     displacement     weight
                no.      direction      factor

                 1           X          1.000

------    A L L O C A T E D    D A T A    S P A C E    ------

                              Integer         Real
                               data           data

           Total              200000        2500000

           Used                10743          19747

           Max no. of elements to develop
           plastic hinges at mid-span is        4305
           (requires additional data storage)
```

Figure 8.2 Input verification

```
-----     N O D A L    P O I N T    D A T A     -----

NPEX    NP        X             Y             Z         BOUN.COND.

   1     1        .000000       .000000      8.382000
   2     2       1.524000       .000000      8.382000
   3     3       3.048000       .000000      8.382000
   :     :         :            :             :
  11    11       3.048000       .000000       .762000
  12    12        .000000       .000000       .000000  X X X X   X
  13    13       3.048000       .000000       .000000  X X X X   X


-----     E L E M E N T     D A T A     -----

ELEX  ELNO   ELTYP    GEOM   MATER     NP1     NP2   LCOOR  ECCEN1  ECCEN2

   1     1    BEAM       4       1       6       5       1       0       0
   2     2    BEAM       4       1       7       6       2       0       0
   3     3    BEAM       4       1       4       6       3       0       0
   :     :      :        :       :       :       :       :       :       :
  21    21    BEAM       1       2       8      11      21       0       0
  22    22    BEAM       1       2      10      12      22       0       0
  23    23    BEAM       1       2      11      13      23       0       0


-----     L O C A L    C O O R D I N A T E   S Y S T E M S     -----

ELEX  LCNO          LOCAL-X               LOCAL-Y               LOCAL-Z

   1     1    .707   .000   .707   .000  1.000   .000  -.707   .000   .707
   2     2    .707   .000   .707   .000  1.000   .000  -.707   .000   .707
   3     3    .707   .000  -.707   .000  1.000   .000   .707   .000   .707
   :     :    :      :      :      :       :       :      :      :      :
  21    21    .000   .000 -1.000 -1.000   .000   .000   .000  1.000   .000
  22    22    .000   .000 -1.000 -1.000   .000   .000   .000  1.000   .000
  23    23    .000   .000 -1.000 -1.000   .000   .000   .000  1.000   .000


-----     G E O M E T R Y    P A R A M E T E R S    -----

  GEO  TYP     Area       Ixx       Iyy       Izz

                          Sect.     Sect.     Sect.   Sh. area  Sh. area
                          mod-x     mod-y     mod-z    y-axis    z-axis

   1  PIPE  7.101E-03  1.782E-04 8.908E-05 8.908E-05
                       1.125E-03 7.160E-04 7.160E-04 3.552E-03 3.552E-03

   :    :    :          :         :         :
                        :         :         :         :         :

   5   I/H  1.570E-01  1.449E-04 6.045E-02 1.519E-02
                       3.435E-02 9.372E-02 3.761E-02 8.128E-02 3.418E-02


-----     M A T E R I A L    P A R A M E T E R S    -----

MAT  TYP    Youngs     Poiss.     Yield     Density    Thermal
            modul.      ratio     stress                expan.

  1   1    2.100E+11  3.000E-01  2.480E+08  7.850E+03  1.400E-05
  :   :     :          :          :          :          :
  3   1    2.100E+11  3.000E-01  3.240E+08  7.850E+03  1.400E-05
```

Figure 8.3 Structural data

8.1.3 Global History Output

The global history output give an overview of the total, global behaviour of the structure during loading. Load, displacement, energy and structural stiffness are listed at each loadstep, with the formation or removal of element plastic hinges.

The formation of plastic hinges is listed at each load step. This is of particular interest to determine the redistribution of forces throughout the structure, and to isolate the elements that trigger the final collapse.

The global history output is shown in Figure 8.4.

```
========     U S F O S     A N A L Y S I S     R E S U L T S      ========

                           Z A Y A s  FRAME
                     U S F O S  progressive collapse analysis
                    S I N T E F  div  of  Structural  Engineering


USFOS
load    Load      Load    Current     Control     Energy       Elem.  Event  Event
comb.   step     level     stiff.      displ.     absorb.       no.   type    pos.

   1     1       1.000    1.000    4.380E-03    8.760E+01
   1     2       2.000    1.000    8.760E-03    3.504E+02
   1     3       3.000    1.000    1.314E-02    7.885E+02
   1     4       4.000    1.000    1.752E-02    1.402E+03
   1     5       5.000    1.000    2.190E-02    2.190E+03
   1     6       5.500    1.000    2.409E-02    2.650E+03
   1     7       5.923    1.000    2.595E-02    3.074E+03
                                                          6   PLAST   END1
   1     8       6.099     .948    2.676E-02    3.270E+03
                                                          8   PLAST   END2
   1     9       6.489     .887    2.869E-02    3.754E+03
                                                          1   PLAST   END2
   1    10       6.500     .865    2.874E-02    3.769E+03
   1    11       6.535     .865    2.892E-02    3.815E+03
                                                          3   PLAST   END1
   1    12       6.585     .837    2.918E-02    3.884E+03
   1    13       6.609     .836    2.931E-02    3.917E+03
                                                          3   PLAST    MID
   1    14       6.631     .785    2.943E-02    3.949E+03
                                                          3   UNLOD   END1
                                                          1   PLAST   END1
                                                          1   PLAST    MID
                                                          1   AXIAL    MID
                                                          2   PLAST    MID
                                                          2   AXIAL    MID
========     U S F O S     A N A L Y S I S     R E S U L T S      ========
```

Figure 8.4 Global history output

USFOS load combination	:	Load combination number, or basic load case number (Section 4.1 and 6.3.D,F).
Load step	:	Number of times the initial load has been incremented.
Load level	:	Relative load level of the current load combination and load step. The load level is "local" within each combination, starting from zero when a new load combination is specified.
Current stiffness	:	Structural stiffness. The initial stiffness is 1.0. Decreasing value represents a decreasing stiffness in the structure (Section 4.2.1).

Control displacement	:	Equivalent displacement of the structure. The displacement is calculated as a balanced average of selected displacements (Section 4.2.2 and 6.3.E).
Energy absorption	:	Accumulated external work absorbed by the structure. This is the total energy of all load combinations.
Element number	:	Element identification number.
Event position	:	Position where a plastic hinge is formed/removed (Section 3.1 and 4.4). END1: First element end END2: Second element end MID : Element midspan JNT1: Joint at first element end JNT2: Joint at second element end
Event type	:	Change of element status. YIELD: The forces has reached first yield of the cross section, and a plastic hinge is formed. (Section 4.3) PLAST: The forces has reached the full plastic capacity of the cross section. UNLOD: The element has unloaded and the cross section has returned to the elastic state. AXIAL: The element forces have reached the full plastic tension capacity of the member. A membrane element is introduced, accounting for geometric stiffness of the member. FRACT: Fracture is detected in the member. JOINT: The full capacity of the joint has been reached and the joint is yielding.
MIN STEP LENGTH	:	Attempt to scale the load step below the minimum size specified by the user. (Section 4.2 and 6.3.D)
MAX DISPL INCR	:	Load step scaled due to large displacement increments. (Section 4.2 and 6.3.D)

The global history output may also be written to the batch-out stream by specifying terminal print adapted to batch running (Section 8.2).

8.1.4 Load Step Output

The load step output give more detailed information of the structural response. At each load step the load, energy and stiffness are listed; interaction function values and status of selected elements; total displacements of specified nodes and global reaction forces of fixed nodes.

Formation/removal of plastic hinges at each element is commented.

The accumulated displacements are printed for all nodes included in the structure "equivalent displacement" calculation (Section 4.2.2) by the command *CNODES* (Section 6.3.E). By specifying a displacement in *CNODES* and setting *dfact* = 0, that displacement will be neglected in the equivalent displacement, but the nodal displacements will still be printed with the load step output.

```
Load step   1 / 19

========     I N C R E M E N T A L       S O L U T I O N        ========

                     Z A Y A s  FRAME
               U S F O S  progressive collapse analysis
              S I N T E F  div  of  Structural  Engineering


              USFOS load combination no             =    1
              Load step no.                         =   19
              Load increment scaled to
              minimum step length

              Load increment                        =     .050
              New load level                        =    5.939
              Current stiffness parameter           =     .409

              Solution accuracy parameter           =  2.800*E-00005
              Determinant of tangential matrix      =  7.980*E 00523
              Energy absorbtion                     =  3.699*E 00003


--------    I N T E R A C T I O N   F U N C T I O N   V A L U E S  Fb(Fy) ---

   ELEM  ES     Node1         Midspan         Node2

      1                                                  Yield at end 1
      1   5  -.19(  .10)   -.19(  .09)   -.19(  .04)         O---O---+
      2   7  -.15(  .17)   -.18(  .11)   -.06(  .06)         O---O---O
      3                                                  Unloading at end 1
      3                                                  Unloading at midspan
      3                                                  Yield at end 1
      3  -7  -.22(  .01)   -.29(  .04)   -.22(  .15)         O---*---O
      4   7  -.25(  .03)   -.29(  .04)   -.23(  .06)         O---O---O
      5                                                  Yield at end 1
      5   1  -.32(  .00)   -.33( -.01)   -.34( -.02)         O---+---+
      6   1  -.28(  .00)   -.33( -.01)   -.33( -.01)         O---+---+
      7                                                  Yield at end 2
      7   2  -.34( -.03)   -.32(  .00)   -.32(  .00)         +---+---O
      8                                                  Unloading at end 2
      8   5  -.31(  .00)   -.32(  .00)   -.28( -.02)         O---O---+
      9   0  -.64( -.47)   -.72( -.57)   -.74( -.60)
     10   0  -.73( -.58)   -.70( -.55)   -.64( -.46)
     13   0  -.60( -.50)  -1.00(-1.00)   -.60( -.50)
     20   0  -.78( -.70)   -.84( -.78)   -.57( -.43)
     21   0  -.78( -.70)   -.84( -.78)   -.57( -.43)
     22   0  -.51( -.35)   -.71( -.60)   -.90( -.84)
     23   0  -.51( -.35)   -.71( -.60)   -.90( -.84)


--------     G L O B A L   T O T A L   D I S P L A C E M E N T S     --------

   NODE        X-dis      Y-dis      Z-dis      X-rot      Y-rot      Z-rot

      1      2.872E-02   .000E+00  1.772E-03   .000E+00  1.210E-03   .000E+00


--------     G L O B A L     R E A C T I O N     F O R C E S         --------

   NODE        X-for      Y-for      Z-for      X-mom      Y-mom      Z-mom

     12     -1.219E+05   .000E+00 -6.534E+05   .000E+00  1.104E-11   .000E+00
     13     -1.157E+05   .000E+00  6.534E+05   .000E+00  1.440E-11   .000E+00
 TOTAL:     -2.376E+05   .000E+00  2.910E-10

Load step   1 / 19 cpu =    1.90 sec,   Total accumulated cpu =     32.68 sec
```

Figure 8.5 Load step output

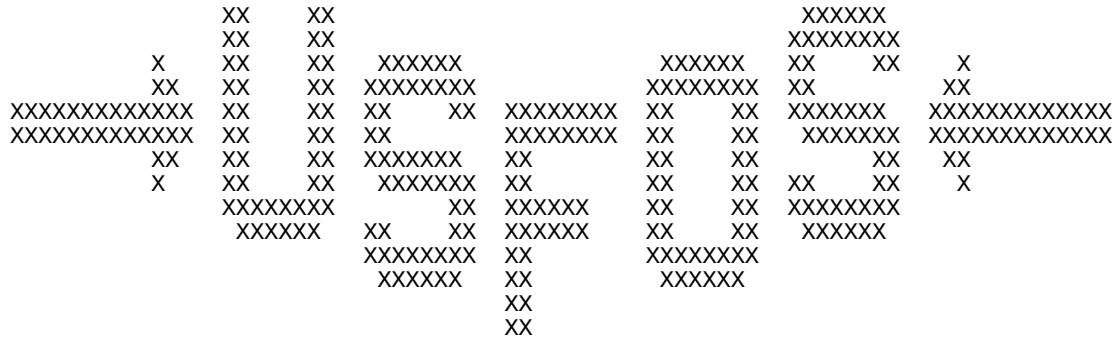
ELEM	:	Element identification number.
ES	:	Element status (Section 4.4).
INTERACTION FUNCTION VALUES	:	(Section 4.3). These values represents the accumulated stress level of each element position with the value -1 in the initial, stress-free configuration, and the value 0 when the first yield capacity or the full plastic capacity is reached. The primary columns concern the full plastic capacity (Value 0 when the full plastic capacity is reached); the secondary column (in brackets) is zero on first yielding of the cross section.
Yield at ... Plastic hinge at ... Unloading at ... Tension failure mode Fracture at ... Capacity lim. at ...	:	Short comments when the status of an element is changed.
... end 1 ... end 2 ... midspan ... joint 1 ... joint 2	:	Position where the element status changes
0---+---+	:	Representation of the element status, corresponding to the value 'ES'. 0 : Plastic hinge inserted. + : Position where element forces are checked for plasticity. * : Plastic hinge removed at element midspan. Internally, the element is still divided in two sub-elements (Section 4.4).
0- -0- -0	:	Plastic tension failure. The axial tension force has reached the plastic capacity, and the current state of forces is maintained during the rest of the analysis (Section 5.2).
GLOBAL TOTAL DISPLACEMENTS	:	This table shows the total accumulated displacements up to and including the current load increment.
GLOBAL REACTION FORCES	:	This table show the total accumulated reaction forces up to and including the current load increment.
NODE	:	Nodal point identification number.

8.2 OUTPUT TO TERMINAL/BATCH-OUT STREAM

Global history output are written to terminal or batch-out stream at each step during analysis. The format of the print is controlled by the parameter *termprint* (Section 6.3.B).

Output for terminal print during interactive running is shown in Figure 8.6.

The data line is overwritten at each load step, except when a local or global load maximum/minimum is detected, i.e. when the current stiffness parameter changes sign.



```
USFOS
 load   Load     Load   Current    Control    Energy
 comb.  step    level    stiff.     displ.    absorb.


    1   23       6.320  -2.405   2.910E-02   3.863E+03
    1   26       6.270    .147   3.203E-02   4.596E+03
    1   41       6.947   -.043   4.771E-02   8.759E+03
 ====================================================
```

Figure 8.6 Terminal output

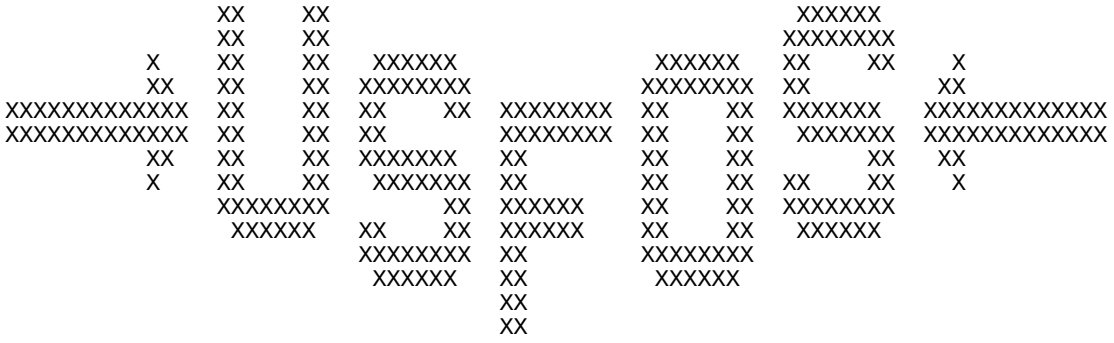
Figure 8.7 shows the print format adapted to batch running. The data corresponds to the global history data for the Analysis Print File (Section 8.1.3).

```
                              - U S F O S -

                          Progressive Collapse
                        Analysis of Frame Structures

                        Version 3.3  /  Release 89-08-25
                      SINTEF div of Structural Engineering


                        Control   file  prefix  : ZAYAS-FRAME-HEAD
                        Structure file  prefix  : ZAYAS-FRAME-STRU
                        Load      file  prefix  :
                        Result    files prefix  : ZAYAS-FRAME
```



```
========     U S F O S     A N A L Y S I S     R E S U L T S      ========

                          Z A Y A s  FRAME
                    U S F O S  progressive collapse analysis
                   S I N T E F  div  of  Structural  Engineering

USFOS
load   Load     Load   Current    Control    Energy       Elem.  Event  Event
comb.  step    level    stiff.     displ.    absorb.       no.   type    pos.

   1    1       1.000   1.000   4.380E-03   8.760E+01
   1    2       2.000   1.000   8.760E-03   3.504E+02
   1    3       3.000   1.000   1.314E-02   7.885E+02
   1    4       4.000   1.000   1.752E-02   1.402E+03
   1    5       5.000   1.000   2.190E-02   2.190E+03
   1    6       5.500   1.000   2.409E-02   2.650E+03
   1    7       5.923   1.000   2.595E-02   3.074E+03
                                                          6   PLAS   NOD1
   1    8       6.099    .948   2.676E-02   3.270E+03
                                                          8   PLAS   NOD2
   1    9       6.489    .887   2.869E-02   3.754E+03
                                                          1   PLAS   NOD2
   1   10       6.500    .865   2.874E-02   3.769E+03
   1   11       6.535    .865   2.892E-02   3.815E+03
                                                          3   PLAS   NOD1
   1   12       6.585    .837   2.918E-02   3.884E+03
   1   13       6.609    .836   2.931E-02   3.917E+03
                                                          3   PLAS    MID

========    U S F O S    A N A L Y S I S    C O M P L E T E D    ========
```

Figure 8.7 Batch output