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# STRATOFEM™ ●

# Usage V1

STRATOFEM™

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# Contents

# Input File Structure

Since this STRATOFEM first version is essentially "FEAST renamed", the input format is as it was defined in 1988, having been influenced from the MARC code input format. It consists of a series of compulsory and optional commands.

**TITLE** (compulsory):

- the title of the problem to be solved

**ANALYSIS** (compulsory): the class of analysis to be done; the user can give any of the following:

- 2D
- 3D
- SHELL

**MATRIX SAVE** (compulsory): whether to save the stiffness matrix for future re-use; the user can give any of the following:

- NOSAVE
- SAVE (not activated for the time being)

**SOLUTION TYPE** (compulsory): the user can give any of the following:

- STATIC
- MODAL (not activated for the time being)

**NUMBER OF LOAD CASES** (compulsory): the number of load cases that can be handled in a single solution; the user can give the following:

- CASE
  - number of load cases

**OUTPUT DETAILS** (compulsory): the amount of information to be included in the printed output, useful ONLY for educational activities; the user can give any of the following:

- BASIC
- PARTIAL (only for very small meshes due to the amount of output generated)
- DETAILED (for educational activities, NOT to be used for more than a handful of elements as the output is colossal, it involves all matrices at each Gauss Point)

**NODAL COORDINATES** (compulsory): definition of the nodal coordinates of the problem.

- COOR

the user can define the format as:

  - FREE
  - FIXED

then give the list of the coordinates for each nodal point, according to the ANALYSIS type.

**NODAL CONNECTIVITY** (compulsory): definition of the nodal connectivity of the problem.

- CONN

then give the element type and associated nodal connectivity for each element.

**MATERIAL PROPERTIES** (compulsory): definition of the material coefficients for each element; for the time being only isotropic elastic materials are allowed.

- ISOT

then give the list of elasticity coefficients for each element with the following choice:

- GROUP
- LIST

**DISTRIBUTED LOADS** (BODY OR SURFACE) (optional): definition of pressure and/or acceleration loads on each element:

- BODY

then give the pressure (for shell elements only) and associated accelerations (along global axes) for each element (all classes of elements) with the following choice:

- GROUP
- LIST

**GEOMETRIC PROPERTIES** (optional): definition of thicknesses etc. depending on the element type used:

- GEOM

the user can choose between

- GROUP
- LIST

**BOUNDARY CONDITIONS** (compulsory): definition of prescribed boundary conditions. They can be a mixture of constrained and/or imposed degrees of freedom.

- BOUN

the prescribed degrees of freedom can be defined with the following choices:

- GROUP
- LIST
- PLANE (over which all the contained nodes will have these conditions imposed)

**POINT LOADS** (optional): definition of the general loadings that can be manifested as point loads along global axes.

- LOAD

the prescribed nodal loads can be defined with the following choices:

- o GROUP
- o LIST

**PROCEDURE TYPE** (compulsory): the user can either proceed with the solution or stop and check the echo of the input for consistency; the user can choose from the following:

- PROCEED
- STOP

## Program Execution

The STRATOFEM™ executable has been compiled for the cygwin system under the Windows environment. Upon execution the user is asked to input the name of the input file. The extension .inp is assumed.

The next question concerns the frequency of information that will be displayed on the screen, in particular how often the user will be informed about which element is processed. **The processing of the first 100 elements is always displayed. This option concerns models with more than 100 elements.**

If for instance the user quotes "10" then STRATOFEM™ will print on the screen the messages that concern elements 110, 120, 130, 140, etc. if of course they exist. In this way for very big inputs with thousands of elements the user can monitor what the program is doing with minimal info. E.g., if the number given is 1000 then the user will get (after the display of the processing of the first 100 elements):

- Creating element 1000
- Assembling element 1000
- Creating element 2000
- Assembling element 2000
- and so on.

Once all the input file has been processed, the size of the problem to solve will have been assessed and STRATOFEM™ shall estimate the RAM memory needed to perform the Gaussian elimination of the stiffness matrix and if the RAM is not sufficient, it will estimate the number of out-of-core blocks to be used and their associated storage size on the disk.

The user will be queried whether this storage size is available for STRATOFEM™ on his disk. If yes, then STRATOFEM™ will proceed with the solution. If not, STRATOFEM™ shall abandon the solution. (Important: this involves SCRATCH files so the user must assign the corresponding location for the creation of these files, otherwise the default might be in Drive C: which is normally reserved for the operating system and should not be saturated.)

If STRATOFEM™ proceeds with the solution, the solution will be accompanied by messages regarding the Creation and Assembly of each element, followed by the Block Matrix Decomposition for each block of the out-of-core solver. Finally, the output will be created for each element and STRATOFEM™ will finish with scratch-file clean-up and closure of important files. As it explained before, in the interest of limiting the on-the-screen messages, all the abovementioned information will be given for a selected number of elements according to the message frequency defined earlier.

The output consists of the:

- Nodal Degrees of Freedom, free or imposed (displacements and rotations depending on the class of analysis)
- Nodal Loads whether imposed or reaction loads (forces and moments depending on the class of analysis)

- Gauss points stresses plus the VonMises equivalent stress, for ALL the Gauss points in EACH element (in case of SHELL, then for the top, middle and bottom layer)
- A summary of the MAX values of the Degrees of Freedom.
- A summary of the MAX and MIN values of all the Gauss point stresses.

# Typical Input

## NAFEMS Benchmark B1_1

```
TAPERED QUADRILATERAL MEMBRANE PLATE - CASE a + CASE b
2D
NOSAVE
STATIC
CASE
     2
BASIC
COORDINATES
FREE
        21
             1  0.              -2
             2  2.000000D+00 -1.500000D+00
             3  2.000000D+00  0.000000D+00
             4  0.000000D+00  0.000000D+00
             5  4.0             -1.0
             6  4.0              0.0
             7  4.0              1.0
             8  2.0              1.5
             9  0.0              2.0
            10  1.0             -1.75
            11  2.0             -0.75
            12  1.0              0.0
            13  0.0             -1.0
            14  3.0             -1.25
            15  4.0             -0.5
            16  3.0              0.0
            17  4.0              0.5
            18  3.0              1.25
            19  2.0              0.75
            20  1.0              1.75
            21  0.0              1.0
CONNECTIVITY
         4         0         8
         1         8    1    2    3    4   10   11   12   13
         2         8    2    5    6    3   14   15   16   11
         3         8    3    6    7    8   16   17   18   19
         4         8    4    3    8    9   12   19   20   21
ISOTROPIC
GROUP
    1
  2.100000D+09  3.000000D-01  7.000000D+03  0.000000D+00  0.000000D+00  6.000000D+02
         1         4         1
END
GEOMETRY
GROUP
    1
  0.100000D+00  0.000000D+00  0.000000D+00  0.000000D+00  0.000000D+00  0.000000D+00
         1         4         1
END
BOUNDARY CONDITIONS
LIST
         5    1 , 1, 1   0.000000D+00
         1   13    4   21    9
         1    2 , 2, 1   0.000000D+00
         4
END LIST
END BOUND
```

```
LOADS
LIST
         2          1          1          1        1.666667D+06    1
         5   7
         2          1          1          1        6.666667D+06    1
        15   17
         1          1          1          1        3.333333D+06    1
         6
END LIST
END LOADS
BODY
GROUP
      1
    0.000000D+00  9.810000D+00  0.000000D+00  0.000000D+00    2
         1    4    1
ENG GROUP
END BODY
PROCEED
```

# Typical Output

## NAFEMS Benchmark B1_1

```
   SSSSSS TTTTTTTTT RRRRRRRRR      AAA     TTTTTTTTT    OOOO     FFFFFFFFFF EEEEEEEEE    MMM    MMM
  SSS     TTTTTTTTT RRRRRRRRR     AA AA    TTTTTTTTT   OO  OO    FFFFFFFFFF EEEEEEEEE    MMMM  MMMM
 SSS      TTTTTTTTT RRR    RR    AA  AA    TTTTTTTTT  OO    OO   FFF        EEE          MM  MM MM  MM
 SSS         TTT    RRR   RRR    AA  AA       TTT     OO    OO   FFF        EEE          MM  MM MM  MM
  SSSS       TTT    RRRRRRRRR    AA  AA       TTT     OO    OO   FFFFF      EEEEE        MM   MMM  MM
   SSSS      TTT    RRRRR        AAAAAAAA     TTT     OO    OO   FFFFF      EEEEE        MM        MM
     SSS     TTT    RRRRRRR     AA    AA      TTT     OO    OO   FFF        EEE          MM        MM
     SSS     TTT    RRR  RRR   AA      AA     TTT     OO    OO   FFF        EEE          MM        MM
   SSS       TTT    RRR   RRR AAA      AAA    TTT      OO  OO    FFF        EEEEEEEEEE MMM         MMM
 SSSSSS      TTT    RRR    RRR AAA     AAA    TTT       OOOO     FFF        EEEEEEEEEE MMM         MMM
```

```
                         *** COMPutational ASsessment Suite ***

                                https://comp-as-s.com/

                          *** PROFESSIONAL VERSION  1.0 ***



                 STRATOFEM IS A TRADEMARK OF "COMPutational ASsessment Suite"


                              L E G A L   N O T I C E
                 THIS COMPUTER CODE MATERIAL (STRATOFEM) SHOULD NOT BE MADE
                 AVAILABLE TO ANY THIRD PARTIES, OTHER THAN THOSE LISTED
                 BELOW, PRIOR TO THE AUTHOR'S  (DR.A.KAMOULAKOS)
                 WRITTEN PERMISION. THE AUTHOR DOES NOT MAKE ANY WARRANTY
                 EXPRESSED OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR
                 RESPONSIBILITY FOR THE ACCURACY,COMPLETENESS OR USEFULNESS
                 OF ANY INFORMATION PROVIDED DIRECTLY OR INDIRECTLY BY STRATOFEM.



                 T H I R D   P A R T I E S :  NONE
1
********************************************************************************************
*              E C H O   O F   T H E   I N P U T    F I L E    B E G I N S               *
********************************************************************************************

TAPERED QUADRILATERAL MEMBRANE PLATE - CASE a + CASE b
2D
NOSA
STAT
CASE
     2
BASI
COOR
FREE
         21
          1       0.000000E+00 -2.000000E+00
          2       2.000000E+00 -1.500000E+00
          3       2.000000E+00  0.000000E+00
          4       0.000000E+00  0.000000E+00
          5       4.000000E+00 -1.000000E+00
          6       4.000000E+00  0.000000E+00
          7       4.000000E+00  1.000000E+00
          8       2.000000E+00  1.500000E+00
          9       0.000000E+00  2.000000E+00
         10       1.000000E+00 -1.750000E+00
         11       2.000000E+00 -7.500000E-01
         12       1.000000E+00  0.000000E+00
         13       0.000000E+00 -1.000000E+00
         14       3.000000E+00 -1.250000E+00
         15       4.000000E+00 -5.000000E-01
         16       3.000000E+00  0.000000E+00
         17       4.000000E+00  5.000000E-01
         18       3.000000E+00  1.250000E+00
         19       2.000000E+00  7.500000E-01
```

```
      20      1.000000E+00  1.750000E+00
      21      0.000000E+00  1.000000E+00
CONN
       4         0         8
       1         8         1         2         3         4        10        11        12        13
       2         8         2         5         6         3        14        15        16        11
       3         8         3         6         7         8        16        17        18        19
       4         8         4         3         8         9        12        19        20        21
ISOT
GROU
       1
  2.100000E+09  3.000000E-01  7.000000E+03  0.000000E+00  0.000000E+00  6.000000E+02
       1         4         1
END
GEOM
GROU
       1
  1.000000E-01  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
       1         4         1
END
BOUN
LIST
       5         1         1         1  0.000000E+00
       1        13         4        21         9
       1         2         2         1  0.000000E+00
       4
END
LOAD
LIST
       2         1         1         1  1.666667E+06         1
       5         7
       2         1         1         1  6.666667E+06         1
      15        17
       1         1         1         1  3.333333E+06         1
       6
END
BODY
GROU
       1
  0.000000E+00  9.810000E+00  0.000000E+00  0.000000E+00         2
       1         4         1
ENG
END
PROC
********************************************************************************************
*            E C H O   O F   T H E   I N P U T   F I L E   E N D S                         *
********************************************************************************************


  TOTAL NUMBER OF ELEMENTS     =         4
  TOTAL NUMBER OF NODES        =        21
  TOTAL NUMBER OF CONSTRAINTS  =         6
  TOTAL NUMBER OF LOAD CASES   =         2
  TOTAL NUMBER OF POINT LOADS  =         5



            N O D A L   C O O R D I N A T E S


     NODE          X-COORD        Y-COORD       Z-COORD
        1          0.0000        -2.0000
        2          2.0000        -1.5000
        3          2.0000         0.0000
        4          0.0000         0.0000
        5          4.0000        -1.0000
        6          4.0000         0.0000
        7          4.0000         1.0000
        8          2.0000         1.5000
        9          0.0000         2.0000
       10          1.0000        -1.7500
       11          2.0000        -0.7500
       12          1.0000         0.0000
       13          0.0000        -1.0000
       14          3.0000        -1.2500
       15          4.0000        -0.5000
       16          3.0000         0.0000
       17          4.0000         0.5000
       18          3.0000         1.2500
       19          2.0000         0.7500
       20          1.0000         1.7500
       21          0.0000         1.0000
```

```
              C O N N E C T I V I T Y    T A B L E


     ELEMENT      TYPE          NODAL CONNECTIVITY
          1        8          1        2        3        4       10       11       12       13
          2        8          2        5        6        3       14       15       16       11
          3        8          3        6        7        8       16       17       18       19
          4        8          4        3        8        9       12       19       20       21



              E L E M E N T   P R O P E R T I E S   T A B L E


     ELEMENT     YOUNGS   POISSON  AVERAGE    YIELD   THICKNESS
                 MODULUS   RATIO   DENSITY   STRESS
          1      2.10E+09 3.00E-01 7.00E+03 6.00E+02 1.00E-01
          2      2.10E+09 3.00E-01 7.00E+03 6.00E+02 1.00E-01
          3      2.10E+09 3.00E-01 7.00E+03 6.00E+02 1.00E-01
          4      2.10E+09 3.00E-01 7.00E+03 6.00E+02 1.00E-01


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


     NODE       DOF     VALUE      NODE      DOF     VALUE      NODE      DOF     VALUE
        1        1    0.000E+00      13        1    0.000E+00        4        1    0.000E+00
       21        1    0.000E+00       9        1    0.000E+00        4        2    0.000E+00


        P R E S C R I B E D   N O D A L   L O A D S   F O R   C A S E    1


     NODE       DOF     VALUE      NODE      DOF     VALUE      NODE      DOF     VALUE
   ELEMENT     SIDE              ELEMENT     SIDE              ELEMENT     SIDE
        5        1    1.667E+06       7        1    1.667E+06       15        1    6.667E+06
       17        1    6.667E+06       6        1    3.333E+06


        P R E S C R I B E D   N O D A L   L O A D S   F O R   C A S E    2


     NODE       DOF     VALUE      NODE      DOF     VALUE      NODE      DOF     VALUE
   ELEMENT     SIDE              ELEMENT     SIDE              ELEMENT     SIDE



      P R E S S U R E   A N D   B O D Y - F O R C E   T A B L E   F O R   C A S E    1


     ELEMENT           AVERAGE                      ACCELERATION
                       PRESSURE            GLOBAL X  GLOBAL Y  GLOBAL Z



      P R E S S U R E   A N D   B O D Y - F O R C E   T A B L E   F O R   C A S E    2


     ELEMENT           AVERAGE                      ACCELERATION
                       PRESSURE            GLOBAL X  GLOBAL Y  GLOBAL Z
          1           0.00E+00             9.81E+00  0.00E+00  0.00E+00
          2           0.00E+00             9.81E+00  0.00E+00  0.00E+00
          3           0.00E+00             9.81E+00  0.00E+00  0.00E+00
          4           0.00E+00             9.81E+00  0.00E+00  0.00E+00



              ****  SIZING STATISTICS ****

   STIFFNESS MATRIX IS   98.89 PERCENT POPULATED

   TOTAL NUMBER OF EQUATIONS                    =          42
   MAXIMUM HALF BANDWIDTH                       =          38
   MINIMUM STORAGE FOR IN-CORE SOLUTION (WORDS) =        1999
   CORE MEMORY AVAILABLE            (WORDS) =   245000000
   APPROX STORAGE FOR OFF-CORE SOLUTION (WORDS) =        1680
   APPROX STORAGE PER BLOCK        (WORDS) =        1680
   TOTAL NUMBER OF BLOCKS                       =           1
   EQUATIONS PER BLOCK                          =          42
   CORE ALLOCATION PER ARRAY       (WORDS) =        1680         168           79



             N O D A L   D I S P L A C E M E N T S   F O R   C A S E    1


   NODE    DOF-1         DOF-2          DOF-3         DOF-4         DOF-5         DOF-6

      1  0.000000D+00  1.968624D-02
      2  4.759671D-02  1.420065D-02
      3  6.245649D-02 -1.934072D-16
      4  0.000000D+00  0.000000D+00
```

```
 5  1.266486D-01  2.517113D-03
 6  1.431047D-01 -3.000014D-16
 7  1.266486D-01 -2.517113D-03
 8  4.759671D-02 -1.420065D-02
 9  0.000000D+00 -1.968624D-02
10  1.958037D-02  1.711693D-02
11  5.889565D-02  8.285012D-03
12  3.108676D-02 -9.973394D-17
13  0.000000D+00  1.178855D-02
14  8.278168D-02  1.308905D-02
15  1.393647D-01  5.357961D-04
16  1.003762D-01 -2.614458D-16
17  1.393647D-01 -5.357961D-04
18  8.278168D-02 -1.308905D-02
19  5.889565D-02 -8.285012D-03
20  1.958037D-02 -1.711693D-02
21  0.000000D+00 -1.178855D-02
```

```
           N O D A L   R E A C T I O N S   F O R   C A S E   1

  NODE       DOF-1        DOF-2        DOF-3        DOF-4        DOF-5        DOF-6

     1   -7.981113D+05  0.000000D+00
    13   -7.197943D+06  0.000000D+00
     4   -4.007892D+06  1.420267D-08
    21   -7.197943D+06  0.000000D+00
     9   -7.981113D+05  0.000000D+00

TOTALS : -2.000000D+07  1.420267D-08
```

```
        E L E M E N T   A N D   G A U S S   P O I N T   S T R E S S E S   F O R   C A S E   1


ELEMENT GAUSS  X-GPT   Y-GPT   Z-GPT   SIGMA 11  SIGMA 22  SIGMA 33  SIGMA 12  SIGMA 13  SIGMA 23  VON MISES
        POINT  COORD   COORD   COORD
   1     1   2.3D-01-1.7D+00 0.0D+00  3.92D+07 -2.69D+06  0.00D+00  1.27D+06  0.00D+00  0.00D+00  4.07D+07
   1     2   1.0D+00-1.6D+00 0.0D+00  4.87D+07 -1.22D+05  0.00D+00  7.24D+06  0.00D+00  0.00D+00  5.03D+07
   1     3   1.8D+00-1.4D+00 0.0D+00  5.88D+07  2.87D+06  0.00D+00  1.22D+07  0.00D+00  0.00D+00  6.12D+07
   1     4   2.3D-01-9.7D-01 0.0D+00  5.29D+07 -4.82D+06  0.00D+00  1.06D+06  0.00D+00  0.00D+00  5.55D+07
   1     5   1.0D+00-8.8D-01 0.0D+00  5.93D+07 -2.75D+06  0.00D+00  4.88D+06  0.00D+00  0.00D+00  6.13D+07
   1     6   1.8D+00-7.8D-01 0.0D+00  6.64D+07 -1.75D+05  0.00D+00  7.13D+06  0.00D+00  0.00D+00  6.76D+07
   1     7   2.3D-01-2.2D-01 0.0D+00  6.08D+07 -8.65D+06  0.00D+00  7.56D+05  0.00D+00  0.00D+00  6.56D+07
   1     8   1.0D+00-2.0D-01 0.0D+00  6.30D+07 -7.45D+06  0.00D+00  2.46D+06  0.00D+00  0.00D+00  6.72D+07
   1     9   1.8D+00-1.8D-01 0.0D+00  6.55D+07 -5.74D+06  0.00D+00  2.05D+06  0.00D+00  0.00D+00  6.87D+07
   2     1   2.2D+00-1.3D+00 0.0D+00  6.14D+07  1.29D+06  0.00D+00  1.79D+07  0.00D+00  0.00D+00  6.82D+07
   2     2   3.0D+00-1.1D+00 0.0D+00  7.23D+07  9.17D+05  0.00D+00  1.70D+07  0.00D+00  0.00D+00  7.77D+07
   2     3   3.8D+00-9.4D-01 0.0D+00  8.68D+07  1.15D+07  0.00D+00  1.50D+07  0.00D+00  0.00D+00  8.57D+07
   2     4   2.2D+00-7.2D-01 0.0D+00  7.05D+07 -3.30D+05  0.00D+00  9.71D+06  0.00D+00  0.00D+00  7.27D+07
   2     5   3.0D+00-6.2D-01 0.0D+00  8.15D+07  2.47D+06  0.00D+00  9.30D+06  0.00D+00  0.00D+00  8.19D+07
   2     6   3.8D+00-5.3D-01 0.0D+00  9.65D+07  1.76D+07  0.00D+00  7.50D+06  0.00D+00  0.00D+00  9.00D+07
   2     7   2.2D+00-1.6D-01 0.0D+00  7.51D+07 -3.34D+06  0.00D+00  2.13D+06  0.00D+00  0.00D+00  7.69D+07
   2     8   3.0D+00-1.4D-01 0.0D+00  8.52D+07  2.38D+06  0.00D+00  2.41D+06  0.00D+00  0.00D+00  8.42D+07
   2     9   3.8D+00-1.2D-01 0.0D+00  9.96D+07  2.16D+07  0.00D+00  1.15D+06  0.00D+00  0.00D+00  9.07D+07
   3     1   2.2D+00 1.6D-01 0.0D+00  7.51D+07 -3.34D+06  0.00D+00 -2.13D+06  0.00D+00  0.00D+00  7.69D+07
   3     2   3.0D+00 1.4D-01 0.0D+00  8.52D+07  2.38D+06  0.00D+00 -2.41D+06  0.00D+00  0.00D+00  8.42D+07
   3     3   3.8D+00 1.2D-01 0.0D+00  9.96D+07  2.16D+07  0.00D+00 -1.15D+06  0.00D+00  0.00D+00  9.07D+07
   3     4   2.2D+00 7.2D-01 0.0D+00  7.05D+07 -3.30D+05  0.00D+00 -9.71D+06  0.00D+00  0.00D+00  7.27D+07
   3     5   3.0D+00 6.2D-01 0.0D+00  8.15D+07  2.47D+06  0.00D+00 -9.30D+06  0.00D+00  0.00D+00  8.19D+07
   3     6   3.8D+00 5.3D-01 0.0D+00  9.65D+07  1.76D+07  0.00D+00 -7.50D+06  0.00D+00  0.00D+00  9.00D+07
   3     7   2.2D+00 1.3D+00 0.0D+00  6.14D+07  1.29D+06  0.00D+00 -1.79D+07  0.00D+00  0.00D+00  6.82D+07
   3     8   3.0D+00 1.1D+00 0.0D+00  7.23D+07  9.17D+05  0.00D+00 -1.70D+07  0.00D+00  0.00D+00  7.77D+07
   3     9   3.8D+00 9.4D-01 0.0D+00  8.68D+07  1.15D+07  0.00D+00 -1.50D+07  0.00D+00  0.00D+00  8.57D+07
   4     1   2.3D-01 2.2D-01 0.0D+00  6.08D+07 -8.65D+06  0.00D+00 -7.56D+05  0.00D+00  0.00D+00  6.56D+07
   4     2   1.0D+00 2.0D-01 0.0D+00  6.30D+07 -7.45D+06  0.00D+00 -2.46D+06  0.00D+00  0.00D+00  6.72D+07
   4     3   1.8D+00 1.8D-01 0.0D+00  6.55D+07 -5.74D+06  0.00D+00 -2.05D+06  0.00D+00  0.00D+00  6.87D+07
   4     4   2.3D-01 9.7D-01 0.0D+00  5.29D+07 -4.82D+06  0.00D+00 -1.06D+06  0.00D+00  0.00D+00  5.55D+07
   4     5   1.0D+00 8.8D-01 0.0D+00  5.93D+07 -2.75D+06  0.00D+00 -4.88D+06  0.00D+00  0.00D+00  6.13D+07
   4     6   1.8D+00 7.8D-01 0.0D+00  6.64D+07 -1.75D+05  0.00D+00 -7.13D+06  0.00D+00  0.00D+00  6.76D+07
   4     7   2.3D-01 1.7D+00 0.0D+00  3.92D+07 -2.69D+06  0.00D+00 -1.27D+06  0.00D+00  0.00D+00  4.07D+07
   4     8   1.0D+00 1.6D+00 0.0D+00  4.87D+07 -1.22D+05  0.00D+00 -7.24D+06  0.00D+00  0.00D+00  5.03D+07
   4     9   1.8D+00 1.4D+00 0.0D+00  5.88D+07  2.87D+06  0.00D+00 -1.22D+07  0.00D+00  0.00D+00  6.12D+07
```

```
        M A X I M A   A N D   M I N I M A : D I S P L A C E M E N T S

          D.O.F.         NODE            VALUE

             1             6          1.431047E-01

             2             9         -1.968624E-02
```

```
            M A X I M A   A N D   M I N I M A : S T R E S S E S

     TYPE         STRESS        ELEMENT         VALUE

      MIN          S11            1          5.717886E+07

      MIN          S22            4         -3.281698E+06

      MIN          S33            1          0.000000E+00

      MIN          S12            3         -9.122241E+06

      MIN          S13            1          0.000000E+00

      MIN          S23            1          0.000000E+00

      MAX          S11            2          8.099763E+07

      MAX          S22            2          6.010477E+06

      MAX          S33            1          0.000000E+00

      MAX          S12            2          9.122241E+06

      MAX          S13            1          0.000000E+00

      MAX          S23            1          0.000000E+00
```

```
        N O D A L   D I S P L A C E M E N T S   F O R   C A S E   2

 NODE    DOF-1        DOF-2        DOF-3        DOF-4        DOF-5        DOF-6

    1  0.000000D+00  6.411107D-05
    2  1.346788D-04  2.181908D-05
    3  1.706340D-04 -4.552861D-19
    4  0.000000D+00  0.000000D+00
    5  2.177818D-04 -3.659823D-06
    6  2.259033D-04 -1.002287D-18
    7  2.177818D-04  3.659823D-06
    8  1.346788D-04 -2.181908D-05
    9  0.000000D+00 -6.411107D-05
   10  6.741156D-05  4.672398D-05
   11  1.652357D-04  1.096784D-05
   12  1.052407D-04 -2.344508D-19
   13  0.000000D+00  3.797999D-05
   14  1.918788D-04  5.733668D-06
   15  2.217411D-04 -2.836617D-06
   16  2.115984D-04 -7.158152D-19
   17  2.217411D-04  2.836617D-06
   18  1.918788D-04 -5.733668D-06
   19  1.652357D-04 -1.096784D-05
   20  6.741156D-05 -4.672398D-05
   21  0.000000D+00 -3.797999D-05
```

```
        N O D A L   R E A C T I O N S   F O R   C A S E   2

 NODE     DOF-1        DOF-2        DOF-3        DOF-4        DOF-5        DOF-6

    1   -3.394110D+03  0.000000D+00
   13   -2.970474D+04  0.000000D+00
    4   -1.620631D+04  3.660716D-11
   21   -2.970474D+04  0.000000D+00
    9   -3.394110D+03  0.000000D+00

 TOTALS : -8.240400D+04  3.660716D-11
```

```
      E L E M E N T   A N D   G A U S S   P O I N T   S T R E S S E S   F O R   C A S E   2


ELEMENT GAUSS  X-GPT    Y-GPT    Z-GPT    SIGMA 11  SIGMA 22  SIGMA 33  SIGMA 12  SIGMA 13  SIGMA 23  VON MISES
        POINT  COORD    COORD    COORD
   1     1   2.3D-01-1.7D+00 0.0D+00  1.54D+05 -1.94D+03  0.00D+00 -1.01D+03  0.00D+00  0.00D+00  1.55D+05
   1     2   1.0D+00-1.6D+00 0.0D+00  1.34D+05 -4.66D+03  0.00D+00  1.42D+04  0.00D+00  0.00D+00  1.39D+05
   1     3   1.8D+00-1.4D+00 0.0D+00  1.22D+05  1.60D+03  0.00D+00  2.13D+04  0.00D+00  0.00D+00  1.26D+05
   1     4   2.3D-01-9.7D-01 0.0D+00  2.03D+05 -4.86D+03  0.00D+00 -4.13D+02  0.00D+00  0.00D+00  2.05D+05
   1     5   1.0D+00-8.8D-01 0.0D+00  1.66D+05 -6.29D+03  0.00D+00  9.25D+03  0.00D+00  0.00D+00  1.70D+05
   1     6   1.8D+00-7.8D-01 0.0D+00  1.35D+05  2.61D+03  0.00D+00  9.24D+03  0.00D+00  0.00D+00  1.35D+05
```

```
1   7   2.3D-01-2.2D-01 0.0D+00  2.34D+05 -1.33D+04  0.00D+00  1.72D+03  0.00D+00  0.00D+00  2.40D+05
1   8   1.0D+00-2.0D-01 0.0D+00  1.75D+05 -1.46D+04  0.00D+00  6.32D+03  0.00D+00  0.00D+00  1.83D+05
1   9   1.8D+00-1.8D-01 0.0D+00  1.21D+05 -4.58D+03  0.00D+00 -2.29D+02  0.00D+00  0.00D+00  1.23D+05
2   1   2.2D+00-1.3D+00 0.0D+00  1.09D+05  6.91D+03  0.00D+00  2.64D+04  0.00D+00  0.00D+00  1.15D+05
2   2   3.0D+00-1.1D+00 0.0D+00  6.64D+04  7.83D+03  0.00D+00  1.70D+04  0.00D+00  0.00D+00  6.94D+04
2   3   3.8D+00-9.4D-01 0.0D+00  2.40D+04  5.97D+03  0.00D+00  5.56D+03  0.00D+00  0.00D+00  2.37D+04
2   4   2.2D+00-7.2D-01 0.0D+00  1.02D+05  5.04D+03  0.00D+00  1.14D+04  0.00D+00  0.00D+00  1.02D+05
2   5   3.0D+00-6.2D-01 0.0D+00  5.75D+04  7.61D+03  0.00D+00  7.63D+03  0.00D+00  0.00D+00  5.57D+04
2   6   3.8D+00-5.3D-01 0.0D+00  1.20D+04  7.82D+03  0.00D+00  4.21D+03  0.00D+00  0.00D+00  1.28D+04
2   7   2.2D+00-1.6D-01 0.0D+00  1.02D+05  5.23D+03  0.00D+00 -3.02D+03  0.00D+00  0.00D+00  9.95D+04
2   8   3.0D+00-1.4D-01 0.0D+00  5.92D+04  1.06D+04  0.00D+00 -1.00D+03  0.00D+00  0.00D+00  5.47D+04
2   9   3.8D+00-1.2D-01 0.0D+00  1.58D+04  1.44D+04  0.00D+00  3.79D+03  0.00D+00  0.00D+00  1.65D+04
3   1   2.2D+00 1.6D-01 0.0D+00  1.02D+05  5.23D+03  0.00D+00  3.02D+03  0.00D+00  0.00D+00  9.95D+04
3   2   3.0D+00 1.4D-01 0.0D+00  5.92D+04  1.06D+04  0.00D+00  1.00D+03  0.00D+00  0.00D+00  5.47D+04
3   3   3.8D+00 1.2D-01 0.0D+00  1.58D+04  1.44D+04  0.00D+00 -3.79D+03  0.00D+00  0.00D+00  1.65D+04
3   4   2.2D+00 7.2D-01 0.0D+00  1.02D+05  5.04D+03  0.00D+00 -1.14D+04  0.00D+00  0.00D+00  1.02D+05
3   5   3.0D+00 6.2D-01 0.0D+00  5.75D+04  7.61D+03  0.00D+00 -7.63D+03  0.00D+00  0.00D+00  5.57D+04
3   6   3.8D+00 5.3D-01 0.0D+00  1.20D+04  7.82D+03  0.00D+00 -4.21D+03  0.00D+00  0.00D+00  1.28D+04
3   7   2.2D+00 1.3D+00 0.0D+00  1.09D+05  6.91D+03  0.00D+00 -2.64D+04  0.00D+00  0.00D+00  1.15D+05
3   8   3.0D+00 1.1D+00 0.0D+00  6.64D+04  7.83D+03  0.00D+00 -1.70D+04  0.00D+00  0.00D+00  6.94D+04
3   9   3.8D+00 9.4D-01 0.0D+00  2.40D+04  5.97D+03  0.00D+00 -5.56D+03  0.00D+00  0.00D+00  2.37D+04
4   1   2.3D-01 2.2D-01 0.0D+00  2.34D+05 -1.33D+04  0.00D+00 -1.72D+03  0.00D+00  0.00D+00  2.40D+05
4   2   1.0D+00 2.0D-01 0.0D+00  1.75D+05 -1.46D+04  0.00D+00 -6.32D+03  0.00D+00  0.00D+00  1.83D+05
4   3   1.8D+00 1.8D-01 0.0D+00  1.21D+05 -4.58D+03  0.00D+00  2.29D+02  0.00D+00  0.00D+00  1.23D+05
4   4   2.3D-01 9.7D-01 0.0D+00  2.03D+05 -4.86D+03  0.00D+00  4.13D+02  0.00D+00  0.00D+00  2.05D+05
4   5   1.0D+00 8.8D-01 0.0D+00  1.66D+05 -6.29D+03  0.00D+00 -9.25D+03  0.00D+00  0.00D+00  1.70D+05
4   6   1.8D+00 7.8D-01 0.0D+00  1.35D+05  2.61D+03  0.00D+00 -9.24D+03  0.00D+00  0.00D+00  1.35D+05
4   7   2.3D-01 1.7D+00 0.0D+00  1.54D+05 -1.94D+03  0.00D+00  1.01D+03  0.00D+00  0.00D+00  1.55D+05
4   8   1.0D+00 1.6D+00 0.0D+00  1.34D+05 -4.66D+03  0.00D+00 -1.42D+04  0.00D+00  0.00D+00  1.39D+05
4   9   1.8D+00 1.4D+00 0.0D+00  1.22D+05  1.60D+03  0.00D+00 -2.13D+04  0.00D+00  0.00D+00  1.26D+05
```

## M A X I M A   A N D   M I N I M A : D I S P L A C E M E N T S

| D.O.F. | NODE | VALUE |
|---|---|---|
| 1 | 6 | 2.259033E-04 |
| 2 | 9 | -6.411107E-05 |

## M A X I M A   A N D   M I N I M A : S T R E S S E S

| TYPE | STRESS | ELEMENT | VALUE |
|---|---|---|---|
| MIN | S11 | 3 | 6.091165E+04 |
| MIN | S22 | 4 | -5.118133E+03 |
| MIN | S33 | 1 | 0.000000E+00 |
| MIN | S12 | 3 | -7.989958E+03 |
| MIN | S13 | 1 | 0.000000E+00 |
| MIN | S23 | 1 | 0.000000E+00 |
| MAX | S11 | 4 | 1.603980E+05 |
| MAX | S22 | 2 | 7.933531E+03 |
| MAX | S33 | 1 | 0.000000E+00 |
| MAX | S12 | 2 | 7.989958E+03 |
| MAX | S13 | 1 | 0.000000E+00 |
| MAX | S23 | 1 | 0.000000E+00 |

```
*************************************************
*          FINAL ELAPSED TIME STATISTICS        *
*************************************************
* PRE-ASSEMBLY I/O      0: 0: 8                  *
* MATRIX ASSEMBLY       0: 0: 0                  *
* PRE-SOLUTION I/O      0: 0: 0                  *
* MATRIX SOLUTION       0: 0: 0                  *
* SOLUTION RECOVERY     0: 0: 0                  *
* STRESS RECOVERY       0: 0: 0                  *
* TOTAL ELAPSED TIME    0: 0: 8                  *
*************************************************
```

COMPutational
ASsessment
Suite

# Appendix 1
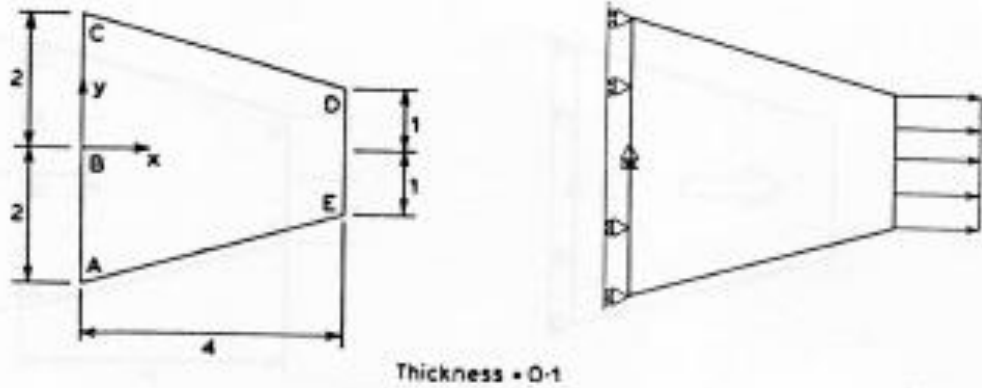
**NAFEMS Benchmark B1_1**

In the previous example, both loadings of the benchmark were applied in one computational run by defining the number of distinct load cases as 2.

| NAFEMS | TAPERED MEMBRANE END LOAD | TEST No IC 1 | DATE/ISSUE |
|---|---|---|---|
| ORIGIN | NAFEMS report LSB2 | | Units M,KN |
| ANALYSIS TYPE | Linear elastic membrane | | |

GEOMETRY



Thickness • 0·1

LOADING — Uniformly distributed horizontal load of 10MN/m (pressure of 100MPa) along outer edge DE

BOUNDARY CONDITIONS — Edge AC zero x displacement
At B zero y displacement
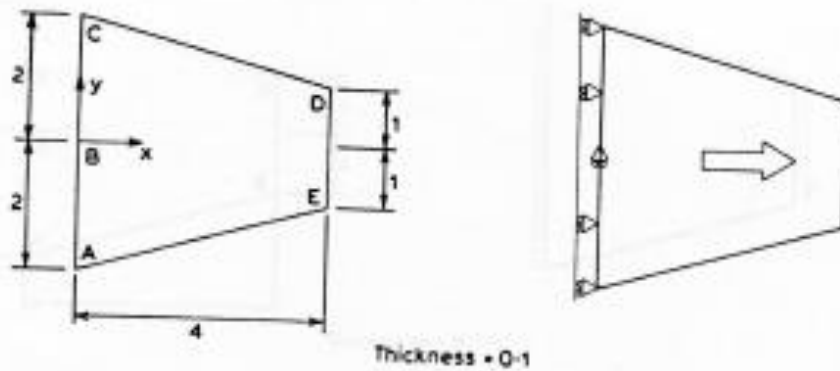
MATERIAL PROPERTIES — Isotropic, E = 210x10³ MPa, v = 0.3

MATERIAL PROPERTIES — Isotropic, $E = 210 \times 10^3$ MPa, $v = 0.3$

ELEMENT TYPES — Plane stress quadrilaterals or triangles

MESHES



2 x 2
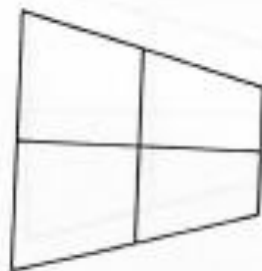uniform
mesh
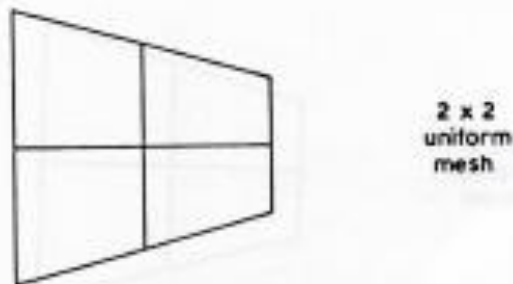
OUTPUT Direct stress $s_{11}$ at B

TARGET     61.3MPa
(mesh refinement)

COMPutational
ASsessment
Suite

| NAFEMS | TAPERED MEMBRANE GRAVITY LOADING | TEST No IC 2 | DATE/ISSUE |
|---|---|---|---|
| ORIGIN | NAFEMS report LSB2 | | Units M,KN |
| ANALYSIS TYPE | Linear elastic membrane | | |
| GEOMETRY | | | |



Thickness = 0·1

LOADING                Uniform acceleration 9.81 M/S² in global
                       x direction (gravity)

BOUNDARY CONDITIONS    Edge AC zero x displacement
                       At B zero y displacement

MATERIAL PROPERTIES    Isotropic, E = 210x10³ MPa,   v = 0.3
                                   p = 7MG/m³

ELEMENT TYPES          Plane stress quadrilaterals or triangles

MESHES



2 x 2
uniform
mesh

OUTPUT   Direct stress $s_x$ at B          TARGET   0.247MPa
                                           (mesh refinement)