DETERMINATION OF INFLUENCE LINES AND SURFACES USING MSC/NASTRAN

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ABSTRACT

This paper presents a simple yet general procedure to determine influence lines and surfaces for frames, beams, trusses, and plates. The method is based on the application of the Muller-Breslau principle and finite elements in combination with standard features of MSC/NASTRAN, a general purpose finite element code.

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INTRODUCTION

Influence lines (IL) and influence surfaces (IS) are commonly used in structural design to determine worst-case locations of live loads. An IL shows the value of a certain quantity (moment, shear, etc.) at a given location of a structure for different positions of a unit load on the structure. For example, the IL for shear at a section of a continuous beam shows the variation in shear at this section as a unit load traverses the structure. An IS, often used in the design of plate structures, is the natural extension of this concept to two-dimensions.

Obviously, determination of influence lines by positioning unit loads at several locations on the structure is impractical. The Muller-Breslau principle, however, provides a more effective way of obtaining influence lines. This principle states the following [1]: "*...the ordinates of the influence line for any action in a structure are equal to those of the deflection curve obtained by releasing the restraint corresponding to this action and introducing a corresponding unit displacement in the remaining structure.*" As an example, consider the beam shown in Figure 1(a). The IL for the bending moment at section A is given by the deformed shape of the beam when an angular displacement equal to one is enforced at A (Figure 1(b)). The ordinate $y(\xi)$ represents the value of the moment at A if a unit load is placed at ξ.

It has been claimed that this principle is not suitable for finite element implementation [2]. This paper shows the contrary, at least within the framework provided by MSC/NASTRAN. It will be seen that determination of ILs or ISs using

MSC/NASTRAN is very straightforward. The following examples demonstrate how to obtain ILs by running MSC/NASTRAN static analysis, either SOLution 24 or 61.

TRUSSES

Consider the truss shown in Figure 2(a) and the corresponding finite element discretization. This example has been taken from [2]. The truss is modeled using 21 ROD elements. It is desired to determine the IL for the force in ROD 3-9, for different positions of a unit vertical load along the bottom cord of the truss.

Proceed as follows:

1) Remove ROD 3-9 from the model.

2) Define a scalar point, say 1000.

3) Define the displacement at scalar point 1000 to be equal to the displacement at GRID (node) 3 in the y-direction minus the displacement at GRID 9 in the y-direction.

4) Enforce a unit displacement at the scalar point (1000).

The Bulk Data Deck statements to achieve this are:

```
SPOINT          1000
MPC     121212          3       2       1.      9       2       -1.     blank   +X
+X      blank   1000    1       -1.
SPC     999999          1000    1       1.
```

The IL is obtained by performing a static analysis. The desired IL (Figure 2(b)) is given by the y-displacement at GRIDs 1 through 7.

BEAMS

Consider the beam structure shown in Figure 3(a). This example has been taken from [3]. The beam is modeled using an array of BAR elements as shown in the figure.

Determination of ILs for reactions is trivial. Consider for example the IL for the reaction at GRID 3. To obtain the IL line it suffices to release the y-displacement at this point and enforce a unit displacement with a SPC card. The following statement needs to be incorporated into the Bulk Data Deck:

```
SPC    777777        3      2      1.0
```

The IL is shown in Figure 3(b).

Determine now the IL for the moment at GRID 8. The procedure is as follows:

1) Define an extra GRID, say, 800, having the same coordinates of GRID 8.

2) Redefine the connectivity of BAR element 8. It must now connect GRIDs 800 and 9.

3) Define a scalar point (1000) to represent the rotation at GRID 8 minus the rotation at GRID 800.

4) Enforce a unit "displacement" (actually a rotation) at the scalar point (1000).

5) Use a multipoint constraint to establish that the displacement in the y-direction at GRID 8 must be equal to the displacement in the y-direction at GRID 800.

This situation is better described in Figure 3(c). The corresponding Bulk Data Deck statements are:

```
SPOINT     1000
MPC  444444       800   6    -1.    8     6     1.     blank  +N
+N   blank  1000  1     -1.
SPC  333333       1000  1    1.
MPC  444444       8     2    1      800   2     -1.
```

The IL is shown in Figure 3(d). It corresponds to the deformed shape of the structure, defined by the displacement vector.

Determination of the IL for shear follows a similar procedure. Consider the IL for shear at GRID 7.

The procedure is as follows:

1) Define an extra GRID, say 700, having the same coordinates of GRID 7.

2) Redefine the connectivity of BAR 7. It must now connect GRIDs 700 and 8.

3) Define a scalar point (1000) to represent the displacement at GRID 700 in the y-direction minus the displacement at GRID 7 in the y-direction.

4) Enforce a unit displacement at scalar point 1000.

5) Use a multipoint constraint to establish that the rotation at GRID 7 must be equal to the rotation at GRID 700.

This situation is depicted in Figure 3(e). The corresponding Bulk Data Deck statements are:

```
SPOINT          1000
MPC     333333          7       2       -1.     700     2       1.      blank   +B
+B      blank   1000    1       -1.
SPC     9999    1000    1       1.
MPC     333333          7       6       1.      700     6       -1.
```

Figure 3(f) shows the IL obtained again performing a simple static analysis.

PLATES

Consider the simply supported plate shown in Figure 4(a). It is modeled using a regular array of 64 QUAD4 plate elements. This example has been taken from [4]. The problem consists of determining the IS for the moment in the x-direction at the center of the plate. The procedure -- a natural extension of the procedure carried out in the case of a beam -- goes as follows:

1) Define an extra GRID, say 82, having the same coordinates of GRID 41.

2) Redefine the connectivity of QUAD4 elements 29 and 37, as indicated in Figure 4(b).

3) Define a scalar point (1000) to represent the y-rotation at GRID 41 minus the y-rotation at GRID 82.

4) Enforce a unit displacement at scalar point 1000.

5) Use a rigid bar to establish that the displacement in the z-direction and the rotation about the x-axis are the same for GRIDs 41 and 82. The same can be achieved with a MPC card.

The corresponding Bulk Data Deck cards are:

```
SPOINT        1000
MPC    444444        82     5      1.     41     5      -1.    blank  +M
+M     blank  1000   1      -1.
SPC    5555   1000   1      1.
RBE2   6666   41     34     82
```

The IS is given by the deformed shape of the plate, which is characterized by the displacement in the z-direction. Figure 4(c) shows the contour plot for the IS.

Extension of this procedure to obtain ILs or ISs more complex structures is rather straightforward.

CONCLUSIONS

A simple procedure to obtain ILs and ISs has been presented. The procedure is based on a direct application of the Muller-Breslau principle and falls within the range of standard capabilities offered by MSC/NASTRAN. This method is much easier to implement than alternative methods described in the literature ([2] and [5]).

REFERENCES

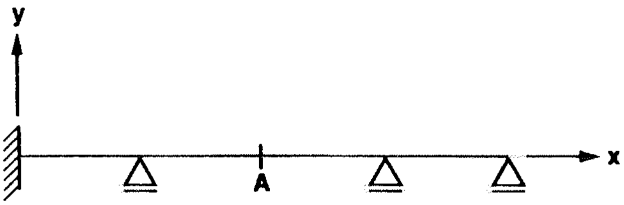
[1] A. Ghali and A.M. Neville, Structural Analysis, Second Edition, John Wiley and Sons, 1978.

[2] A.D. Belegundu, The Adjoint Method For Determining Influence Lines, Computers & Structures, Vol. 29, Number 2, pp 345-350, 1988.

[3] J.C. McCormac, Structural Analysis, Fourth Edition, Harper & Row, 1984.

[4] S. Timoshenko and S. Woinowsky-Krieger, Theory of Plates and Shells, Second Edition, McGraw-Hill Co., 1959.

[5] H. Fu, Indirect Structural Analysis by Finite Element Method, Proc. of the ASCE, Journal of the Structural Division, Vol. 99, Number ST1, January, 1973, pp 91-111.



Continuous Beam

Figure 1(a)

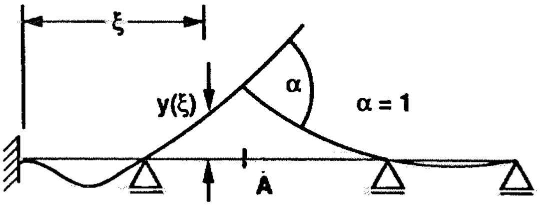
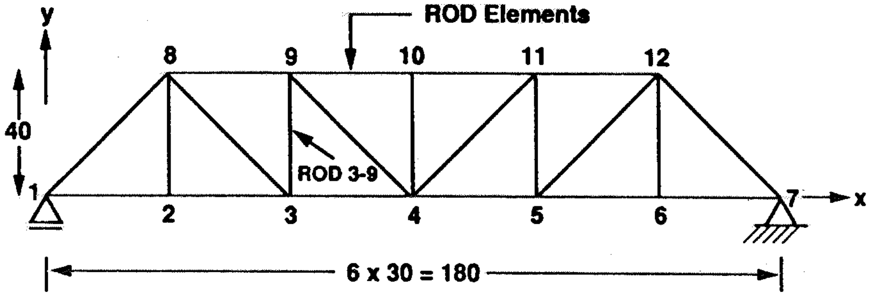


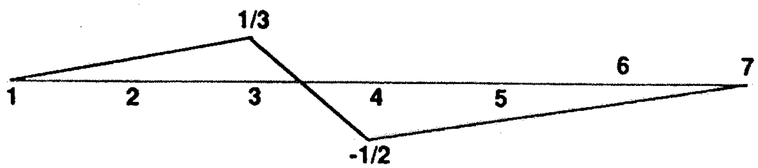
Figure 1(b)

Figure 1. Influence Line for the Moment at Section A.



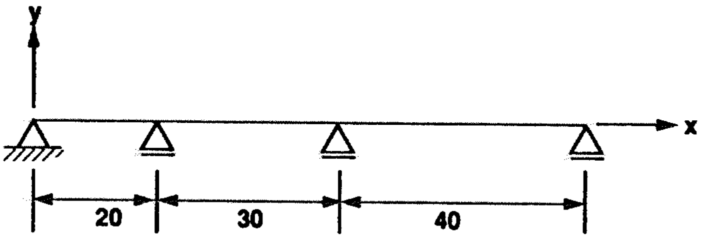
E = 1.0
A = 1.0

Figure 2(a). Plane Truss.



POINT ID.	T1	T2
1	-6.245005E-17	0.0
2	-5.720227E-17	1.666667E-01
3	-5.204170E-17	3.333333E-01
4	-3.816392E-17	-5.000000E-01
5	-2.775558E-17	-3.333333E-01
6	-1.474515E-17	-1.666667E-01
7	0.0	0.0
8	-2.222222E-01	1.666667E-01
9	-2.222222E-01	-6.666667E-01
10	-2.222222E-01	-5.000000E-01
11	-2.222222E-01	-3.333333E-01
12	-2.222222E-01	-1.666667E-01
1000	1.000000E+00	

Figure 2(b). Influence Line for ROD Force in Member 3-9.



E = 1.0
I = 1.0

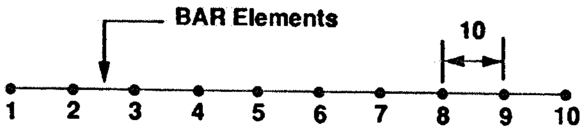
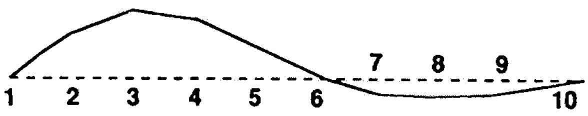
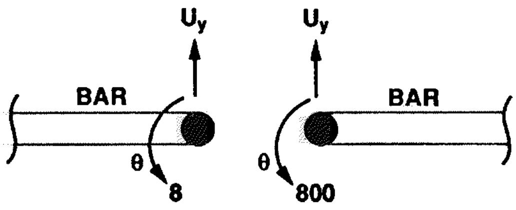


Figure 3(a). Continuous Beam and Finite Element Discretization.



POINT ID.	T2
1	0.0
2	6.450382E-01
3	1.000000E+00
4	8.702290E-01
5	4.427481E-01
6	0.0
7	-2.337786E-01
8	-2.671756E-01
9	-1.669847E-01
10	0.0

Figure 3(b). Influence Line for Reaction at GRID 3.



$U_{y_{800}} = U_{y_8}$

$\theta_8 - \theta_{800} = 1$

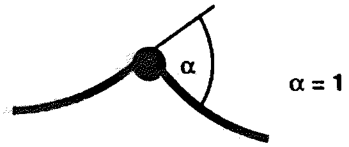
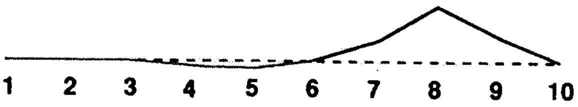
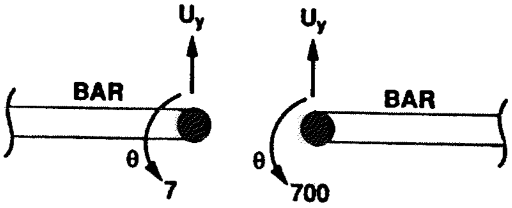


Figure 3(c). Boundary Condition at GRID 8 to Determine Influence Line for Moment.



POINT ID.	T2
1	0.0
2	1.717557E-01
3	0.0
4	-6.361323E-01
5	-9.669211E-01
6	0.0
7	2.996183E+00
8	7.709924E+00
9	3.568702E+00
10	0.0
800	7.709924E+00
1000	1.000000E+00

Figure 3(d). Influence Line for Moment at GRID 8.



$U_{y_{700}} - U_{y_7} = 1$

$\theta_7 = \theta_{700}$

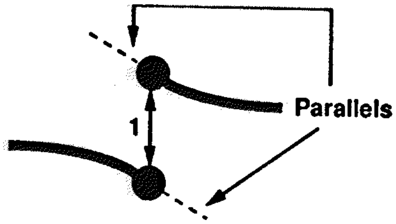
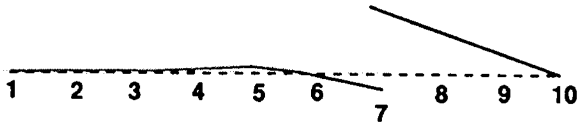
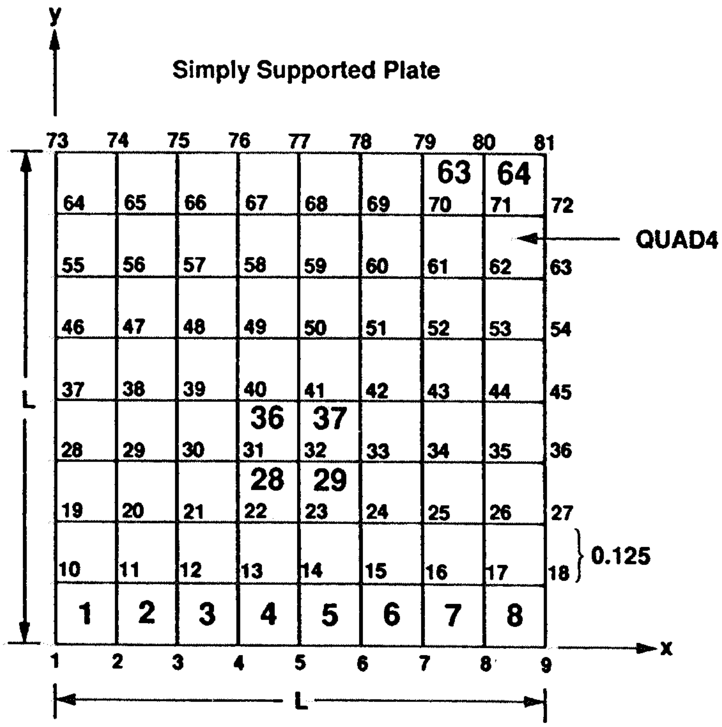


Figure 3(e). Boundary Condition at GRID 7 to Determine Influence Line for Shear



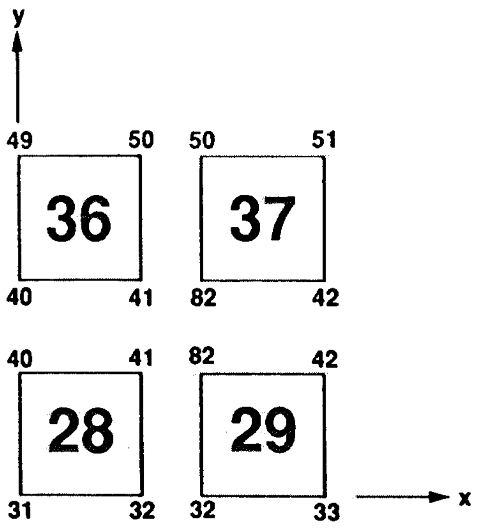
POINT ID.	T2
1	0.0
2	-8.587786E-03
3	0.0
4	3.180661E-02
5	4.734595E-02
6	0.0
7	-1.498092E-01
8	6.145038E-01
9	3.215649E-01
10	0.0
700	8.501908E-01
1000	1.000000E+00

Figure 3(f). Influence Line for Shear at GRID 7.



L = 1.0
E = 10.92
ν = .3
Thickness = 1.0

Figure 4(a). Square Plate and Finite Element Discretization.



$$U_{z_{41}} = U_{z_{82}}$$

$$\theta_{x_{41}} = \theta_{x_{82}}$$

$$\theta_{y_{82}} - \theta_{y_{41}} = 1$$

Figure 4(b). Boundary Condition at GRID 41.

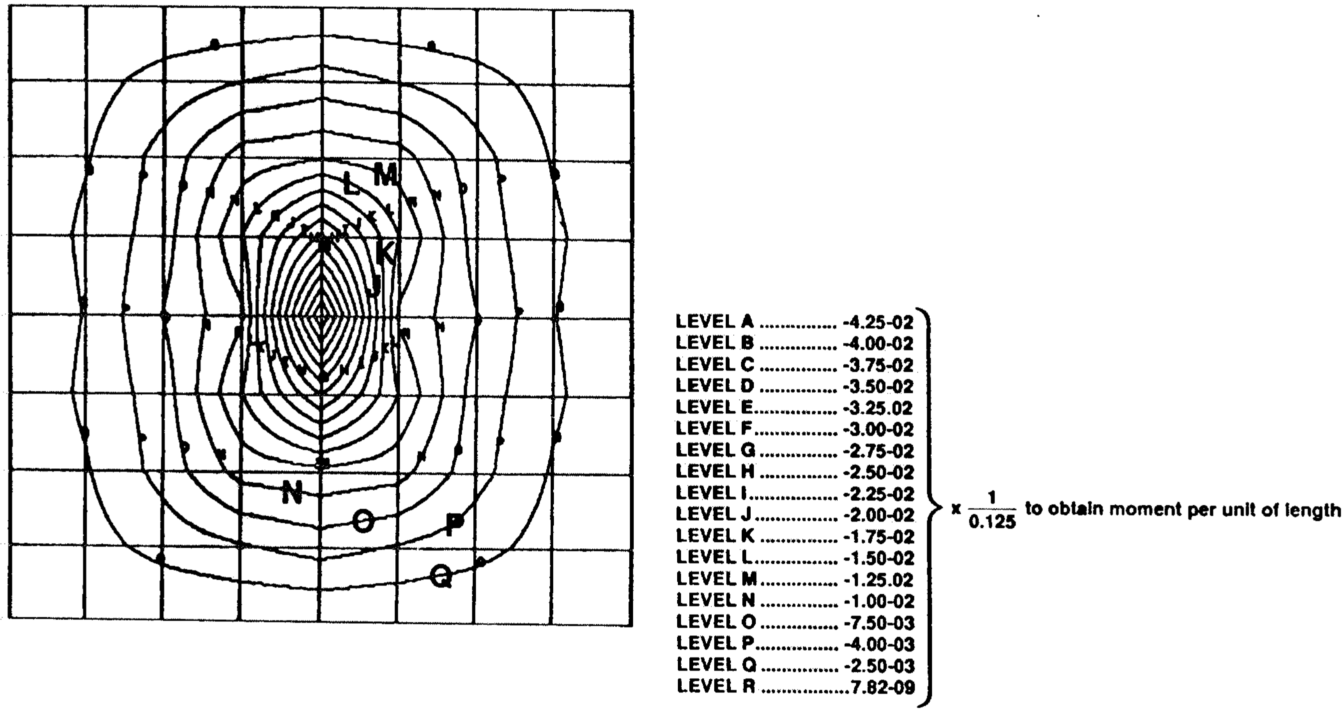


Figure 4(c). Contour Plot of Surface of Influence for M_x at the Center

APPENDIX

MSC/NASTRAN Input Data Deck to determine the influence line for shear. This data deck corresponds to the beam structure described in Figure 3(a). The influence line produced by this deck in shown in Figure 3(f).

```
ID C,C
TIME  4
SOL  61
CEND
TITLE=   INFLUENCE LINES USING MSC/NASTRAN
DISP= ALL
MPC= 4444
SEALL = ALL
ECHO= BOTH
SPC= 9999
OUTPUT(PLOT)
SET 7  INCLUDE ALL
AXES   Z,X,Y
VIEW  0.0,  0.0,  0.0
FIND
PLOT  STATIC DEFORMATION  0 SET 7
BEGIN BULK
PARAM,POST,0
GRID    1                  .0      .0      .0
GRID    2                  10.     .0      .0
GRID    3                  20.     .0      .0
GRID    4                  30.     .0      .0
GRID    5                  40.     .0      .0
GRID    6                  50.     .0      .0
GRID    7                  60.     .0      .0
$
$  EXTRA  POINT
$
GRID    700                60.     .0      .0
$
$
GRID    8                  70.     .0      .0
GRID    9                  80.     .0      .0
GRID    10                 90.     .0      .0
$
$
$
$
CBAR    100     222     1       2       .0      1.      0.
CBAR    200     222     2       3       .0      1.      .0
CBAR    300     222     3       4       .0      1.      .0
CBAR    400     222     4       5       .0      1.      .0
CBAR    500     222     5       6       .0      1.      .0
CBAR    600     222     6       7       .0      1.      .0
```

```
$
CBAR    700     222     700     8       .0      1.      .0
$
CBAR    800     222     8       9       .0      1.      .0
CBAR    900     222     9       10      .0      1.      .0
$
$
$
$
PBAR    222     11      1.      1.
MAT1    11      1.              .3
$
$
$
SPC1    9999    1345    1       THRU    10
SPC1    9999    1345    700
SPC1    9999    1       1
SPC1    9999    2       1       3       6       10
$
$
$
$
$  SCALAR POINT (1000) TO REPRESENT RELATIVE DISP AT 7
$
SPOINT  1000
$
$  ENFORCE, ROTATION AT 7 =  ROTATION AT 700
$
MPC     4444    7       6       1.      700     6       -1.000
$
$  DEFINE  SCALAR POINT 1000=   DISP AT 700 - DISP AT 7
$
MPC     4444    7       2       -1.00   700     2       1.              +NNNN
+NNNN           1000    1       -1.
$
$  ENFORCE   DISPLACEMENT AT POINT 1000 = 1.000
$
SPC     9999    1000    1       1.000
$
ENDDATA
```