Enveloping Results of Multiple Load Cases

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Abstract

Many structures such as those used in the aerospace and the automotive industry are subjected to multiple load conditions. Software has been developed to scale, combine, and sort stresses, forces, and displacements from a few unit load cases. The procedure saves creating and running many load cases, requires much less plotting, and prevents errors of omission. A launch load event of 128 combinations can be analyzed from 7 unit load cases combined into a single plot. This technology is now available as MSC/PATRAN shareware.

Introduction

In many products, loads may act in any of several directions with alternating signs and in concert with other loads. For instance, a product might be subject to loads of +/-Ax, +/-By, and +/-Cz where the x, y, and z loads act simultaneously. For an asymmetric structure, that would require 8 subcases to be run to analyze the problem. If rotational loads of +/-Drx, +/-Ery, and +/-Frz along with a temperature range of +/-GΔT are added to the above set, the resulting number of subcases is $2^7 = 128$. This combination of loads is common for payloads of launch vehicles in the aerospace industry. In fact, typically the lateral loads can be in any direction in the yz plane, requiring even more subcases to describe loads acting at every 30 degree increment. The above set of loads would describe liftoff, with additional sets for booster separation, and other launch events. The burden in stress analysis to run, evaluate, plot and document all of these cases is high. Stress contour plots for a single case in a detailed model require significant post-processing time.

In an effort to reduce the labor required, a post-processing program was developed to automate the process. The user is required to run only unit load cases, 7 in the above example (+1x, +1y, +1z, +1rx, +1ry, +1rz, +1dT). The post-processing program reads those results, makes all possible combinations, records peak values, and stores the results. It is then possible to make a single stress plot, which is the peak over all load cases. Several other options are described in the paper. This capability has been added to the MSC/PATRAN shareware utilities.

Problem Statement

Reduce the effort required to search over all possible load combinations to find peak response results. Provide a concise, single result plot of the peak response envelope.

Analysis

All of the capabilities described in this report have been incorporated into a Fortran program called Sigmax. Some of the most important capabilities are available as MSC/PATRAN shareware.

The analyst must create unit load subcases in MSC/NASTRAN for each load condition, typically 1g in each coordinate direction, corresponding angular accelerations, and a unit temperature change. The ASCII punch file is used as the output format to facilitate cross-platform analyses.

The primary purpose of the program is to scan all possible combinations of loads and report the peak response in every element or grid point desired. Load combinations (Loadcom) are defined as:

$$L_k = \Sigma_j F_{kj} * S_j$$

where

L_k = kth created Loadcom, Lid = k (M = total number)
S_j = jth unit subcase/mode, Sid = j (N = total number)
F_{kj} = user-specified scale factors (M*N = total number)

The type of combinations available are:

* linear combinations
* envelopes
* rss, rms
* random response

In a linear combination, the user specifies each Loadcom to be searched by providing each F_{kj}. The search can provide the peak results over *each* Loadcom (M sets of results) or the peak over *all* Loadcoms (1 set of results). This is useful for a limited number of combinations or as a check of the maximum condition found in the envelope option.

For the envelope option, the user provides the max and min values of F for each subcase and the program creates all possible combinations. For N unit subcases, there will be 2^N Loadcoms created. Multiple envelope sets (S) are available to account for different loading events. The search can provide the peak results over *each* Loadcom ($M = S * 2^N$ sets of results) or the peak over *all* Loadcoms (1 set of results).

The rss option combines by root-sum-squared method rather than addition:

$$L = \text{sqrt} [\Sigma_j (F_j * S_j)^2]$$

whereas the rms option combines by root-mean-squared method:

$$L = \text{sqrt} [(1/N) \Sigma_j (F_j * S_j)^2]$$

The rss and rms options are typically used for acoustic effects, which are then superimposed on static effects in the envelope option.

In the random response method, an efficient modal approach described in [1] is implemented. MSC/NASTRAN solution 103 is used to provide natural frequencies (ω_n), eigenvectors (Φ), and modal results such as eigenstress (σ). Sigmax then calculates the transfer function (H) and PSD (S) of the response:

$$H(s) = \Sigma_j \, [\, (\Phi_j^T * F) * \sigma \, / \, (s^2 + 2 * \xi_j * \omega_j * s + \omega_j^2) \,]$$

$$S(f_k) = |H(f_k)|^2 \, W(f_k)$$

where $\Phi_j^T * F$ is the modal force, ξ_j is modal damping, and W is the PSD of the applied load. The summation is conducted over all modes at each frequency step. It is much easier and more efficient to use this approach than the conventional MSC/NASTRAN random response approach. Version 70.5 has a new random response features which may provide a convenient method inside MSC/NASTRAN.

Results types that are currently sorted on within Sigmax include:

* element stress
* element force
* grid displacements
* SPC forces
* MPC forces

In element stress, the directional stresses are scaled and combined at each recovery point, then the Von Mises stress and principal stresses are recalculated. For all of the other results types, user-defined vector combinations are optional. Thus, the net shear force in a bar,

$$F_{net} = \text{srqt} \, [\, F_y^2 + Fz^2 \,]$$

or the maximum grid rotation

$$R_{net} = \text{srqt} \, [\, R_x^2 + R_y^2 + R_z^2]$$

are optional outputs.

When the peak results are presented, the Lid number of the load combination at which it occurs is listed. Thus, users can easily find which are the critical load combinations. If the search had been over a large number of envelope conditions, the user could rerun Sigmax on the critical Lid condition(s) using the linear combination option to study an individual case.

In almost all cases, the peak responses do not occur simultaneously. For example, when the maximum axial force occurs, the bending moments may not be maximum. Thus, assuming envelope peaks occur together can be overly conservative. An option for a “consistent” set of output has been added to Sigmax. In this output, a complete response set is printed for each maximum value. For bar forces, the output would be a matrix for each element, where the diagonal (underlined) is the peak response and the remaining terms in the row are the forces in that element occurring at the same time. Vector combinations (Vj) are included in the matrix.

Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2
Fx	Fy	Fz	Mx	My	Mz	V1	V2

MSC/NASTRAN features supported include subcoms, repcases, and superelements with both compressed or expanded subcase structure.

Example Problem

A simple example problem of a shell structure similar to common telescopes is shown in Figure 1. The 3-legged spider at the top supports a lumped mass. The shell is supported at 3 points around the circumference. Two sets of envelope loads represent 2 launch conditions. Each set is limited to g loads along coordinate directions. The total number of load combinations checked is:

$$2 \text{ sets} * 2^3 \text{ combinations/set} = 16 \text{ combinations}$$

The resulting output tables are shown in the appendix. The contour plot shown in Figure 2 represents the envelope of peak values and not a single load condition.

MSC/PATRAN Implementation

MSC/PATRAN shareware has been developed to create and search the multiple load combinations created by the envelope option. To use the shareware just pick on "envelope". A new form will pop up for selecting the unit cases and defining the envelope factors. Linear combinations are already available through "combine results".

Future Developments

Both Sigmax and the MSC/PATRAN shareware should be able to utilize the new (version 70.5) MSC/NASTRAN random PSD response output. If the new capability is efficient and available in the punch file, then Sigmax will add the option to read the rms results rather than recalculate them. The shareware will be extended to read other element types and other response quantities.

Conclusions

The procedure described in this paper allows for efficient and complete searching over a large number of possible load combinations. Peak response values and the loads that cause them are listed for each grid point or element. This allows a single plot to completely represent the envelope of peak values occurring over several events. Many of the features have been implemented in MSC/PATRAN shareware.

Recommendations

When using MSC/PATRAN to post-process externally generated results, the data must be written in fixed format files for nodal or element results. The formats are very limiting and user unfriendly. The number of rows and columns must be specified in advance. Any labeling must be done in separate template files. Only one set of results can be included in a file.

I would suggest that the free-format external file used in MSC/XL be implemented. In this file, integers and reals can be mixed in free format. The number of rows and columns are never specified. Labeling is included in the top of the file. Any number of sets of results can be included in a single file. MSC already has the code, so why not embed it in MSC/PATRAN.

References

1. Sweitzer, K., Bishop, N., and Halfpenny, A., *Efficient Computation of Structural Fatigue Caused by Random Loading Sources*, Proc of Int. Conf. on Noise and Vibration Engineering, ISMA, 1998.

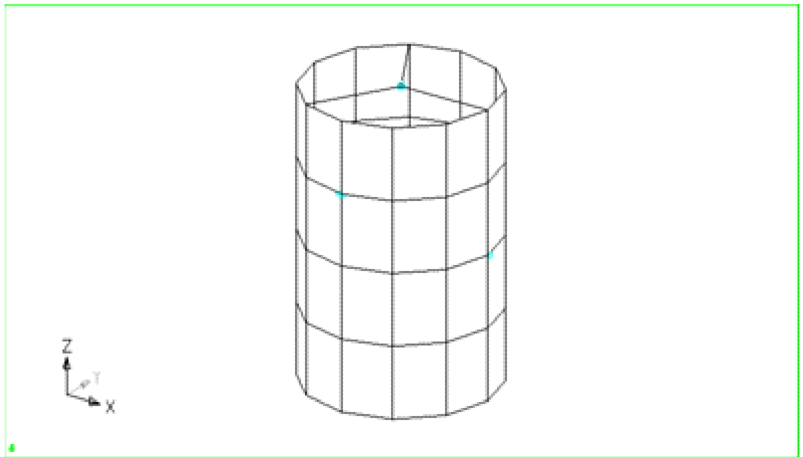

Figure 1: Example Shell Structure

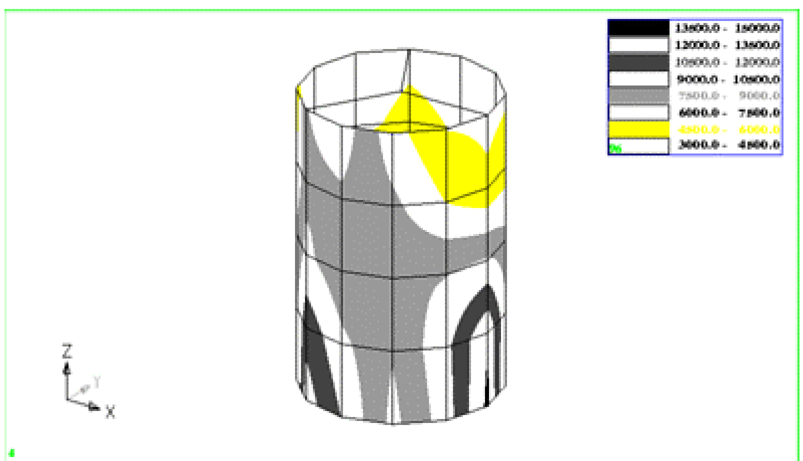

Figure 2: Envelope of Peak Stress Results

Appendix

```
    SigMaX - Results Sorting (truncated)
 ----------------------------------------------------------------------
    Load Factors - for each Subcase/Mode
    Lid       1       2       3
      1    8.00    8.00   12.00
      2    8.00    8.00   -9.00
      3    8.00   -8.00   12.00
      4    8.00   -8.00   -9.00
      5   -8.00    8.00   12.00
      6   -8.00    8.00   -9.00
      7   -8.00   -8.00   12.00
      8   -8.00   -8.00   -9.00

      9   10.00   11.00    9.00
     10   10.00   11.00   -8.00
     11   10.00  -11.00    9.00
     12   10.00  -11.00   -8.00
     13  -10.00   11.00    9.00
     14  -10.00   11.00   -8.00
     15  -10.00  -11.00    9.00
     16  -10.00  -11.00   -8.00
----------------------------------------------------------------------
    Peak STRESS over ALL  Subcase/Mode combinations
    Sorted stress output on Directional components
    Max=Most Pos, Min=Most Neg, Abs=Max Absolute Value
    Number ranked in decreasing order = 10

Rank     Eid_Lid__Sx-Max        Eid_Lid__Sx-Min
   1     229   9  1.404E+04     229  16 -1.381E+04
   2     233   9  1.272E+04     233  16 -1.247E+04
   3     230   9  1.241E+04     230  16 -1.226E+04
   4     213  11  1.166E+04     213  14 -1.163E+04
   5     217  11  1.153E+04     217  14 -1.150E+04
   6     231   9  1.098E+04     231  16 -1.088E+04
   7     245  15  1.001E+04     243  11 -9.942E+03
   8     243  14  9.914E+03     245  10 -9.688E+03
   9     201  13  9.816E+03     201  12 -9.490E+03
  10     239  11  8.504E+03     239  14 -8.396E+03

 ----------------------------------------------------------------------
    Sorted stress output on Principal components

Rank     Eid_Lid__S1-Max        Eid_Lid__Sv-Max
   1     229   9  1.429E+04     245  15  1.406E+04
   2     245  15  1.391E+04     201  13  1.356E+04
   3     201  13  1.327E+04     246  15  1.343E+04
   4     233   9  1.306E+04     229   9  1.321E+04
   5     230   9  1.260E+04     230   9  1.280E+04
   6     213  11  1.216E+04     202  13  1.234E+04
   7     217  11  1.188E+04     233   9  1.217E+04
   8     231   9  1.112E+04     213  11  1.144E+04
   9     243  14  9.937E+03     236   9  1.137E+04
  10     246  15  8.989E+03     217  11  1.101E+04

 ----------------------------------------------------------------------
```

Sigmax Example Output

```
MSC/XL .ext file format (truncated and edited)
--------------------------------------------------------------------------------
!#Title: Ext file written by SigMaX
!#columnalias: 1 Eid
!#columnalias: 2 SxLid1
!#columnalias: 3 SxMax
!#columnalias: 4 SxLid2
!#columnalias: 5 SxMin
  ...
!#columnalias:16 SvLid
!#columnalias:17 SvMax
  ...
! Title=SIMPLE EXAMPLE FOR SIGMAX
! Subtitle=TELESCOPE WITH QUAD4 AND BAR
! Max=Most Pos, Min=Most Neg, Abs=Max Absolute Value
! Max STRESS in every Plate element
! Eid Lid__Sx-Max    Lid__Sx-Min    Lid__S1-Max    Lid__S2-Min    Lid__Sv-Max
  201  13  9.816E+03  12 -9.490E+03  13  1.327E+04  12 -1.300E+04  13  1.356E+04
  202   5  4.948E+03  12 -4.274E+03  11  8.036E+03  14 -7.925E+03  13  1.234E+04
  203   9  4.635E+03  16 -4.542E+03   9  5.905E+03  16 -5.834E+03   9  5.285E+03
  204   1  1.662E+03  16 -1.396E+03  11  2.934E+03  14 -2.860E+03   9  4.253E+03
  205  10  1.069E+03   7 -1.197E+03  12  2.972E+03  13 -3.025E+03  13  4.093E+03
  ...
```

MSC/XL ext file

```
MSC/PATRAN .els file format (truncated)
--------------------------------------------------------------------------------
 SIMPLE EXAMPLE FOR SIGMAX
    8
 TELESCOPE WITH QUAD4 AND BAR
   SUBID =         1
     201
  0.98156E+04 -0.94902E+04  0.34387E+04 -0.34027E+04  0.60993E+04  0.13267E+05
 -0.13003E+05  0.13556E+05
     202
  0.49482E+04 -0.42740E+04  0.30555E+04 -0.30397E+04  0.61224E+04  0.80359E+04
 -0.79254E+04  0.12336E+05
     203
  0.46354E+04 -0.45424E+04  0.28875E+04 -0.28835E+04  0.22095E+04  0.59051E+04
 -0.58336E+04  0.52853E+04
     204
  0.16620E+04 -0.13961E+04  0.14010E+04 -0.13872E+04  0.22311E+04  0.29342E+04
 -0.28602E+04  0.42527E+04
     205
  0.10691E+04 -0.11972E+04  0.81090E+03 -0.80141E+03  0.23175E+04  0.29720E+04
 -0.30245E+04  0.40925E+04
  ...
--------------------------------------------------------------------------------
```

MSC/PATRAN els file