Software Tools for Analysis of Bonded Joints

Farhad Tahmasebi, Ph.D.

NASA/GSFC - Code 542

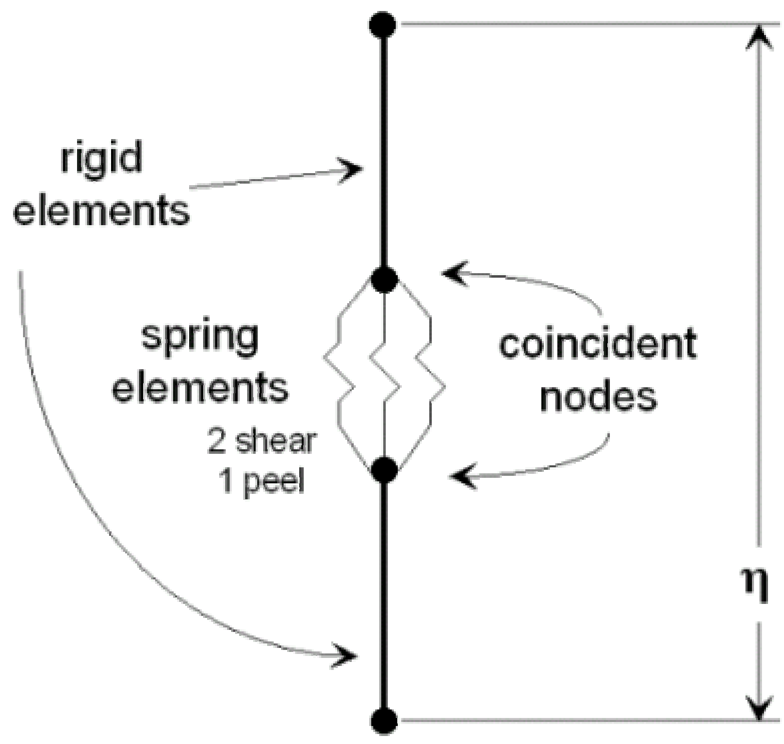
Outline

- Spring modeling
  - Procedure
  - Spring stiffness values
- Description of the adhesive stress program
- Description of the adhesive strain program
- Inputs to & outputs from the programs
  - NASTRAN input & output files $\Rightarrow$ Program inputs
- Mathematica 3D plots

Spring Modeling Procedure (1/3)

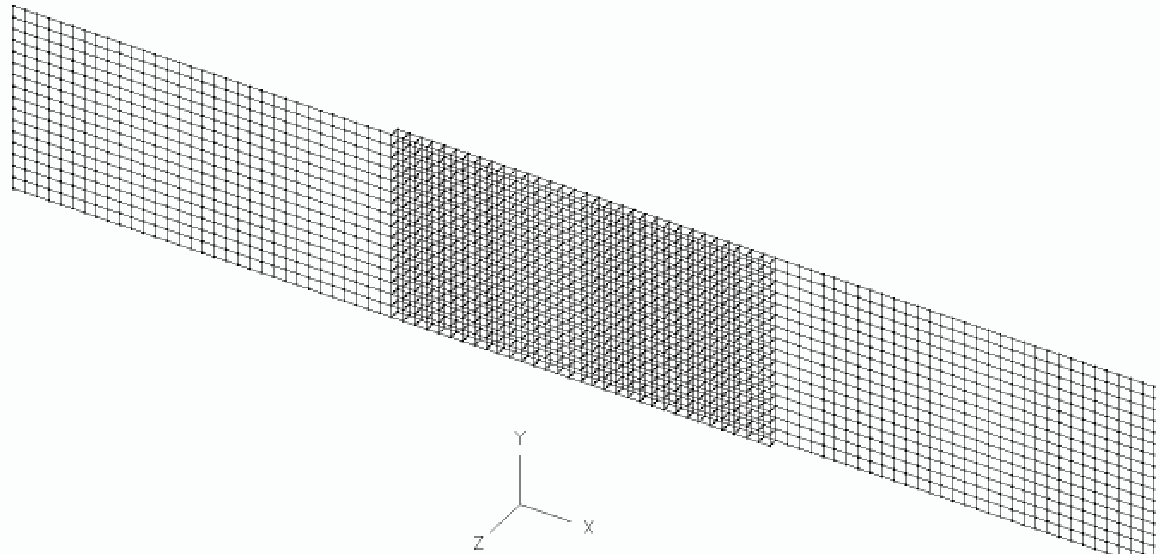
- A fine mesh of grids is created in the mid-plane of the bonded joint.
- For every grid in the mid-plane mesh, an initially-coincident grid is created.
- Three springs are placed between each pair of initially-coincident
- grids.
  - These springs act in the X, Y, and Z directions.
    * X and Y axes are parallel to the overlap plane of the bonded joint.
    * Z axis is defined by the right-hand-rule.
- Rigid elements are used to connect the mid-plane grids to the corner grids of the plate elements which represent the adherends.

Spring Modeling Procedure (2/3)

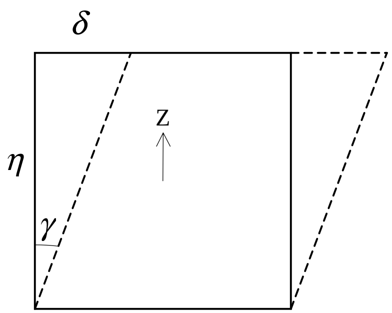


Spring Modeling Procedure (3/3)

3 springs act between each pair of initially-coincident grids on the mid-plane of the adhesive.



Spring Stiffness Values (Shear)



$$\tau = G\gamma \quad ; \quad \tau = \frac{V}{A} \quad ; \quad \delta = \gamma\eta \quad \therefore \quad \frac{V}{A} = G\frac{\delta}{\eta}$$

$$V = K_s\delta \quad \therefore \quad K_s = \frac{GA}{\eta}$$

$$Note: A = A_{internal} = 2A_{edge} = 4A_{corner}$$

Symbol	**Description**
τ	Adhesive shear stress
G	Adhesive shear modulus
γ	Adhesive shear strain
V	Shear force
A	Element area
δ	Shear deflection
η	Adhesive thickness
K_s	Shear spring stiffness

Spring Stiffness Values (Peel)

$$\sigma = E\varepsilon \quad ; \quad \sigma = \frac{P}{A} \quad ; \quad \varepsilon = \frac{\Delta}{\eta} \quad \therefore \quad \frac{P}{A} = E\frac{\Delta}{\eta}$$

$$P = K_P \Delta \quad \therefore \quad K_p = \frac{EA}{\eta}$$

$$Note: A = A_{internal} = 2A_{edge} = 4A_{corner}$$

$$E_{\text{internal}} = E_a = 2G(1+\nu)$$

$$E_{\text{edge}} = \frac{E_a(1-\nu)}{1-\nu-2\nu^2}$$

$$E_{\text{corner}} = \frac{E_a}{1-\nu^2}$$

Symbol	**Description**
σ	Adhesive peel stress
E_a	Adhesive elasticity modulus
E	Effective elasticity modulus
ν	Adhesive Poisson's ratio
ε	Adhesive peel strain
P	Peel force
A	Element area
Δ	Peel deflection
η	Adhesive thickness
K_p	Peel spring stiffness

Description of the Adhesive Stress Program (1/2)

- 1 - Prompts the user for the name of NASTRAN input and output files.
- 2 - Locates and stores all of the spring ID's, the corresponding grid ID's, and the corresponding grid coordinates in the NASTRAN input file.
- 3 - Identifies the pairs of grids which are coincident in the unloaded model.
- 4 - Identifies the spring triplets (X, Y, and Z) for the pairs of initially-coincident grids.
- 5 - Locates and stores the spring forces in the corresponding NASTRAN output file.

Description of the Adhesive Stress Program (2/2)

- 6 - Assigns the stored spring forces to the appropriate springs in the triplets identified in step 4.
- 7 - Determines adhesive shear and peel stresses at the mid-plane grids using the following equations.

$$\tau_i = \frac{\sqrt{f_{x,i}^{2} + f_{y,i}^{2}}}{A} \quad and \quad \sigma_i = \frac{f_{z,i}}{A} \quad where \;\; i = grid\ number$$

- 8 - Sorts the shear and peel stresses in descending order and writes them to an output file.
- 9 - Writes the coordinates of the mid-plane grid points and their corresponding shear and peel stresses to plot files.

Description of the Adhesive Strain Program (1/2)

- Starts by executing steps 1 through 4 that the Adhesive Stress program goes through. Next, performs the following operations.
- 1 - Locates and stores the mid-plane grid point displacements in the NASTRAN output file.
- 2 - Calculates and stores the adhesive spring deformations from the grid point displacements obtained in the previous step.
- 3 - Assigns the stored spring deformations to the appropriate elements in the spring triplets corresponding to the pairs of initially-coincident grids

Description of the Adhesive Strain Program (2/2)

- 4 - Calculates adhesive shear and normal strains at the mid-plane grids using the following equations.

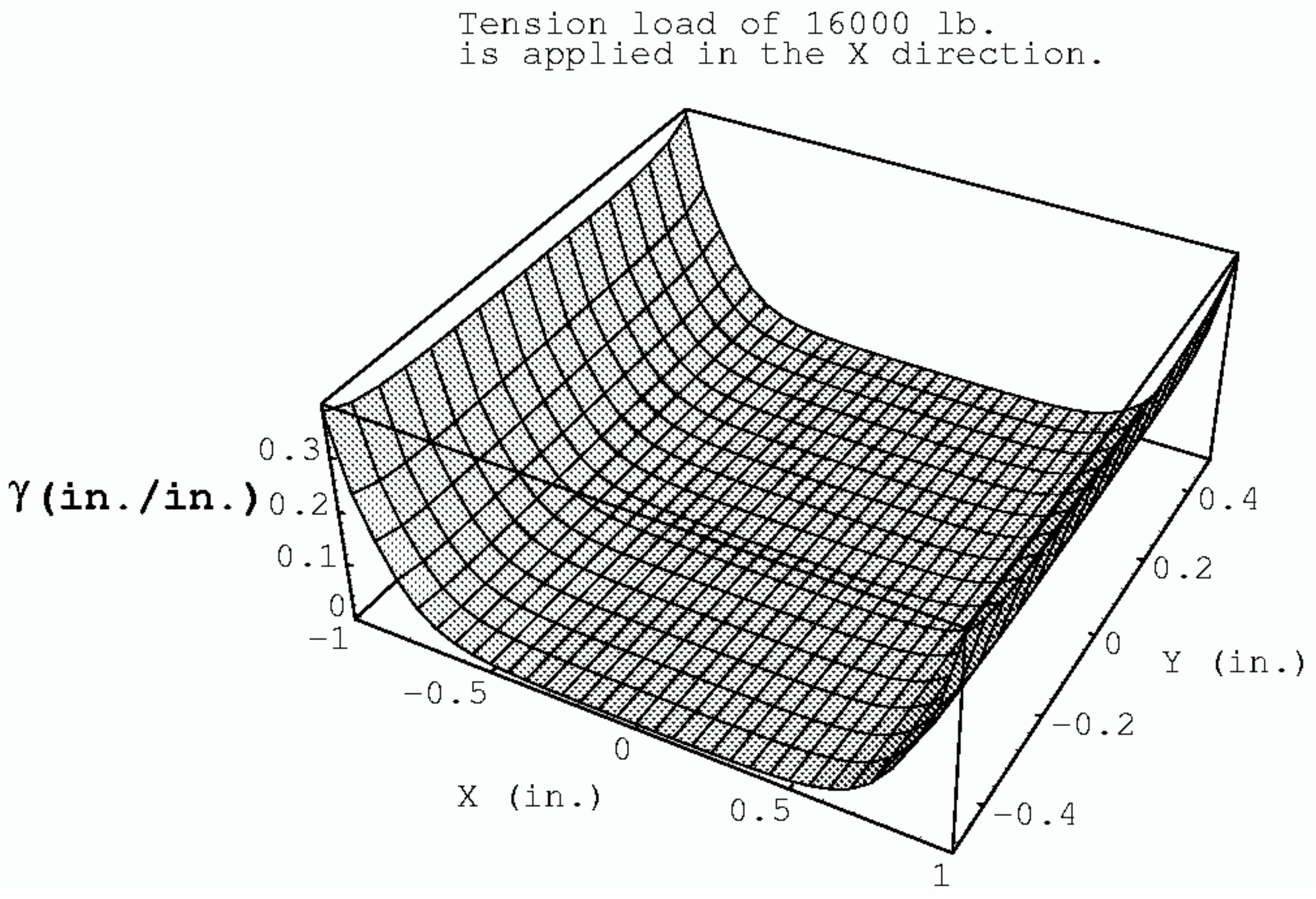
$$\gamma_i = \frac{\sqrt{\delta_{x,i}^2 + \delta_{y,i}^2}}{\eta} \quad \textit{and} \quad \varepsilon_i = \frac{\delta_{z,i}}{\eta} \quad \textit{where } \; i = \textit{grid number}$$

- 5 - Sorts the shear and normal strains in descending order and writes them to an output file.
- 6 - Writes the coordinates of the mid-plane grid points and their corresponding shear and normal strains to plot files.

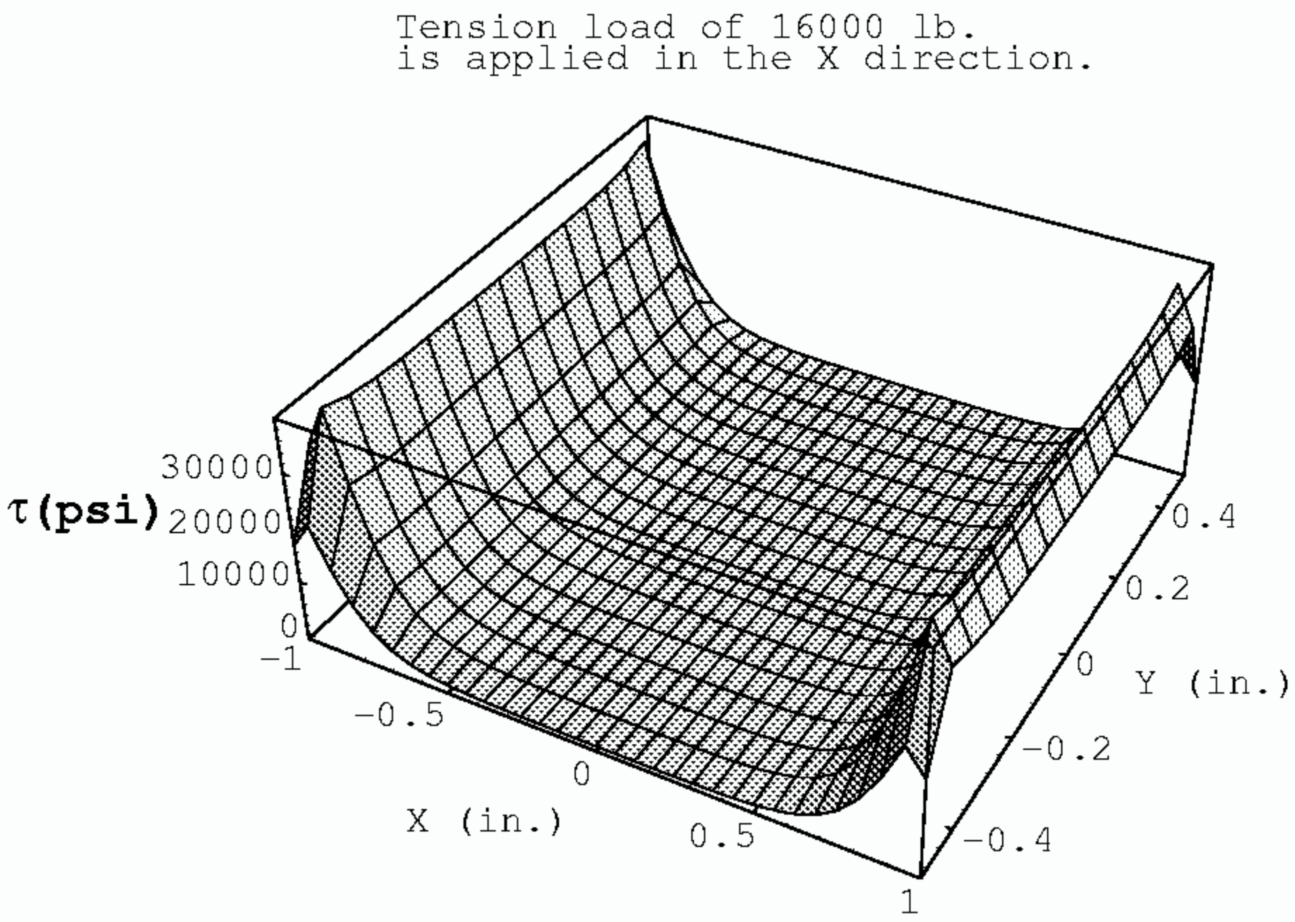
Inputs & Outputs

- Inputs
  - NASTRAN input file
  - NASTRAN output file
    - * Spring forces
    - * Displacements of the adhesive mid-plane grids
  - Element area (adhesive stress program)
  - Adhesive thickness (adhesive strain program)
- Outputs
  - .ad_strs (sorted stresses) & .ad_strn (sorted strains) files
  - .tau, .sigma, .gamma, & .epsilon Mathematica plot files
- <u>*The grids and springs can be numbered in any order.*</u>

Sample 3D Mathematica Plot (Shear Strain)



Sample 3D Mathematica Plot (Shear Stress)



Sample Output File (.ad_strn)

```
No. of spring grids = 561
Grids:  8001  9001  => Gamma=  0.3811, and Epsilon=  -0.1195
Grids:  8002  9002  => Gamma=  0.2440, and Epsilon=   0.0419
Grids:  8003  9003  => Gamma=  0.1677, and Epsilon=   0.0734
.
.
.
******** SORTED SHEAR STRAINS **********
Grids:  8033  9033 => Gamma=   0.3848
Grids:  8561  9561 => Gamma=   0.3848
Grids:  8001  9001 => Gamma=   0.3811
.
.
.
******** SORTED PEEL STRAINS **********
Grids:  8099  9099 => Epsilon=   0.1797
Grids:  8495  9495 => Epsilon=   0.1797
Grids:  8462  9462 => Epsilon=   0.1786
.
.
.
```

Sample Output File (.ad_strs)

```
No. of springs = 1683. No. of points = 561
Springs:  4002  5683  5684  => Tau= 17050.4878, and Sigma=  5020.4877
Springs:  4005  5685  5686  => Tau= 21762.8052, and Sigma= -3518.7251
Springs:  4008  5687  5688  => Tau= 14779.8012, and Sigma= -6167.9155
.
.
.
******** SORTED SHEAR STRESSES **********
Springs:  4194  5811  5812  => Tau= 38807.8485
Springs:  5580  6735  6736  => Tau= 38807.8485
Springs:  5490  6675  6676  => Tau= 38713.2117
.
.
.
******** SORTED PEEL STRESSES **********
Springs:  4200  5815  5816  => Sigma= 15544.5325
Springs:  5388  6607  6608  => Sigma= 15544.5325
Springs:  5289  6541  6542  => Sigma= 15004.5107
.
.
.
```

References

- K.R. Loss and K.T. Keyward, Modeling and Analysis of Peel and Shear Stresses in Adhesively Bonded Joints, AIAA paper 84-0913.
- L.J. Hart-Smith, Adhesive-Bonded Double-Lap Joints, Technical Report NASA CR112235, Contract NAS1-11234, McDonnell Douglas/Douglas Aircraft Co., Jan. 1973.
- L.J. Hart-Smith, Design Methodology for Bonded-Bolted Composite Joints, Final Technical Report AFWAL-TR-81-3154, Vol. I, Contract F33615-79-C-3212, McDonnell Douglas/Douglas Aircraft Co., Feb. 1982.