Creep Modeling Using Plate Theory

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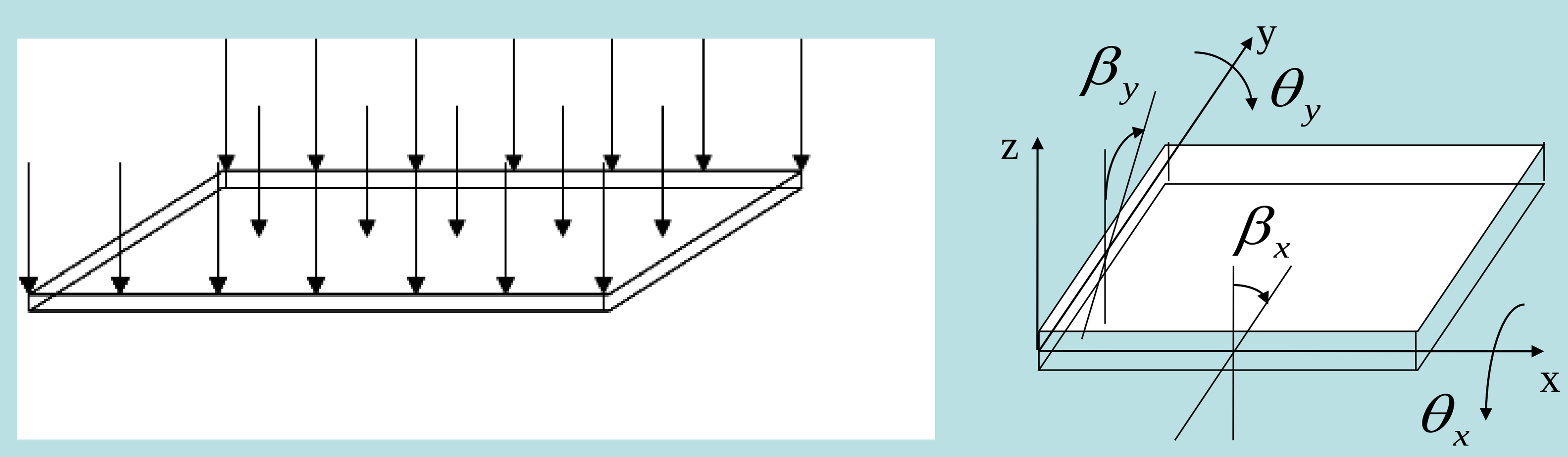
Objective: To Model Creep in RF MEMS Devices Using Finite Volume Method (FVM) Based Mindlin-Reissner Plate Theory

- Use finite volume method to study creep deformation of RF MEMS devices using Mindlin-Reissner plate theory
- Implement a general non-linear stress-strain rate constitutive law in the FVM plate model to characterize any creep mechanism
- Study creep in fixed-fixed plates for a range of aspect ratios to study the applicability of plate model for RF MEMS
- Compare accuracy and CPU cost for creep modeling with plate model and full 3D FVM structural model
- Study Coble creep in nanocrystalline nickel RF MEMS devices
- Compare numerical result for long-term creep behavior of frogleg device with experimental data

Plate Model Overview



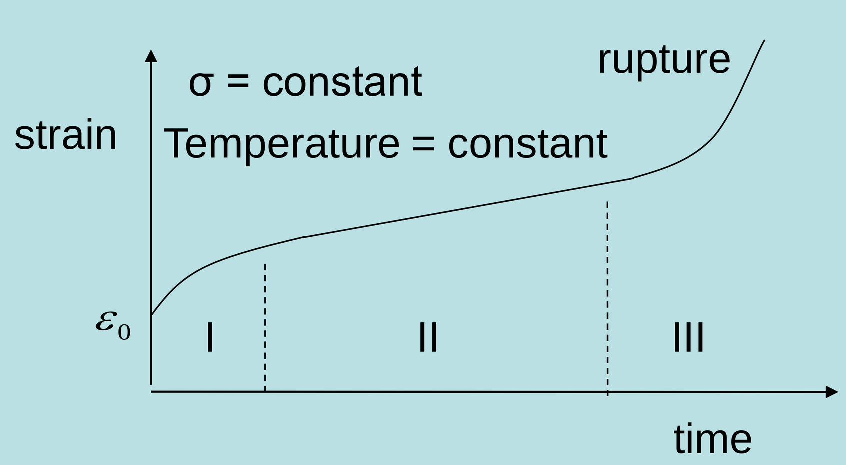
- Solve for vertical deflections and rotations about x and y axes
- Balance moments about x and y axes and force along the z-axis
- Assume plastic deformation occurs only due to bending

$$\sum M_x = 0 \qquad \sum M_y = 0 \qquad \sum F_z = 0$$

$$\varepsilon = \varepsilon^e + \varepsilon^p$$

- Completely linearize elastic part of stress tensor
- Model contribution due to creep using an explicit Euler procedure
- Resolve plate thickness to store stress and plastic strains

Creep Modeling



$$\dot{\varepsilon}_c = A\left(\frac{\sigma}{\sigma_y}\right)^m$$

$$\sigma_y = \sigma_{y0}\left(1 + B\left(\varepsilon_c^{eff}\right)^n\right)$$

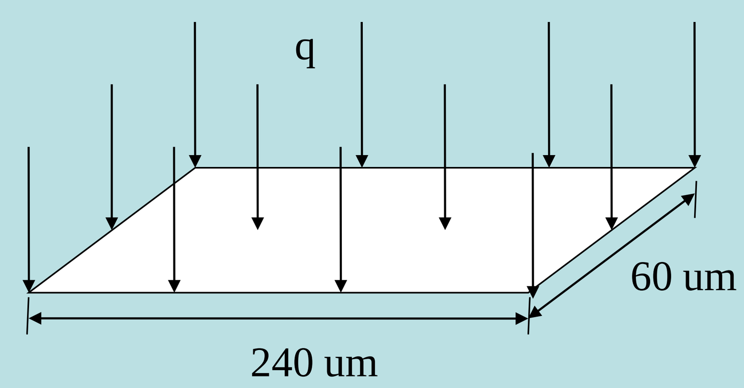
- Stage I characterized by decreasing creep rate
- Stage II characterized by steady-state creep rate, and lasts longest
- Stage III characterized by rapidly increasing creep rate

Different creep mechanisms identified with different values of creep stress exponent m

m = 1: Diffusion Creep
m = 2: Grain-Boundary Sliding
m > 3: Power-law creep

At room temperature, Coble creep most important in nc-Ni

Creep in Fixed-Fixed Plates

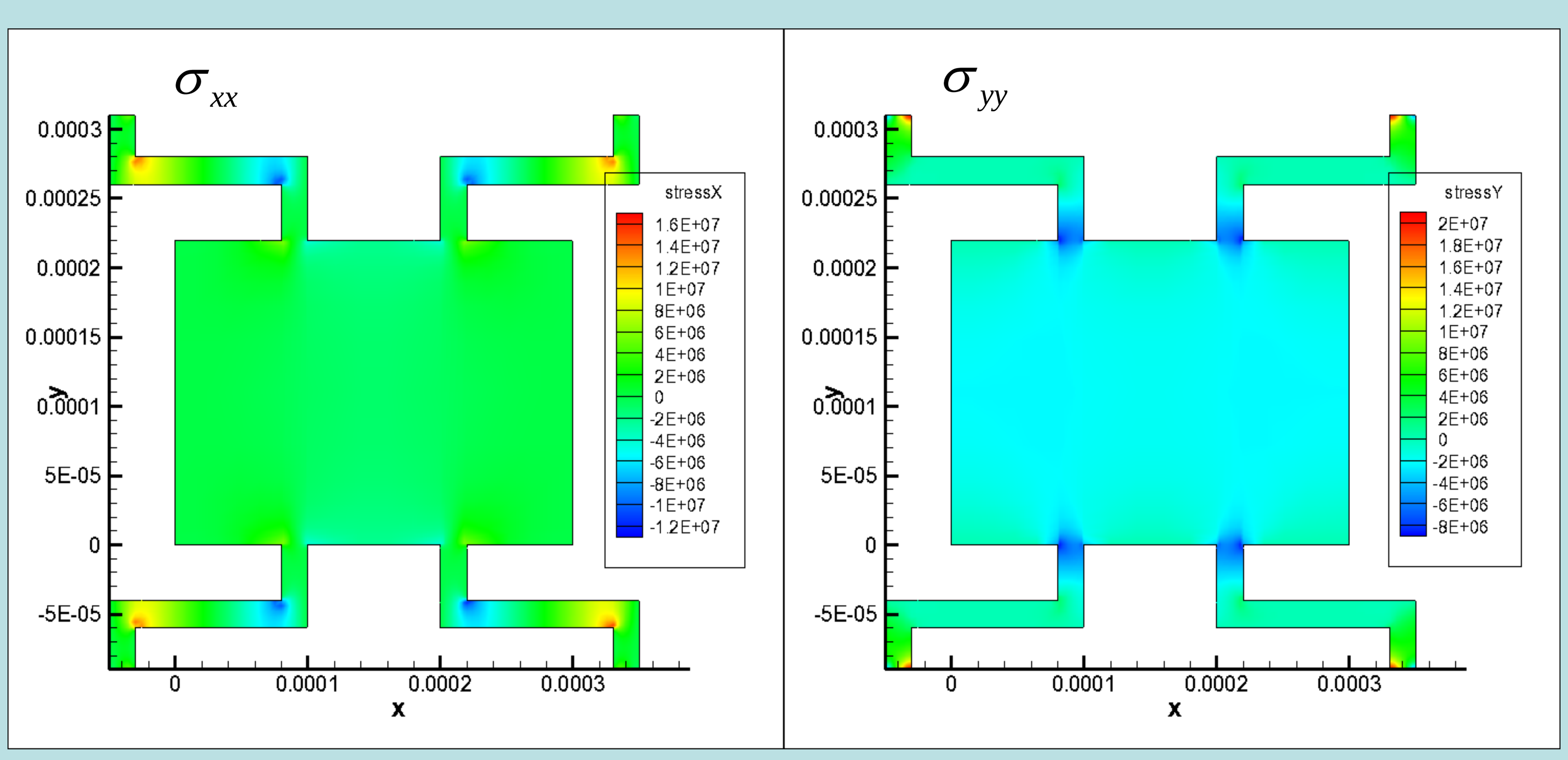


- Plate model accurately predicts creep for thin RF MEMS devices
- The computational advantage with plate model over full 3D FVM structural model increases with an increase in aspect ratio

Percentage error in creep deformation at time t = 500 hrs

L/h	Percentage Error	Plate Model CPU Time (hrs)	Structural Model CPU Time (hrs)
10	16.76	0.03	3.85
20	4.32	0.03	7.36
30	0.15	0.03	13.76
40	0.42	0.03	34
50	0.24	0.03	47.14
60	0.5	0.03	97.43

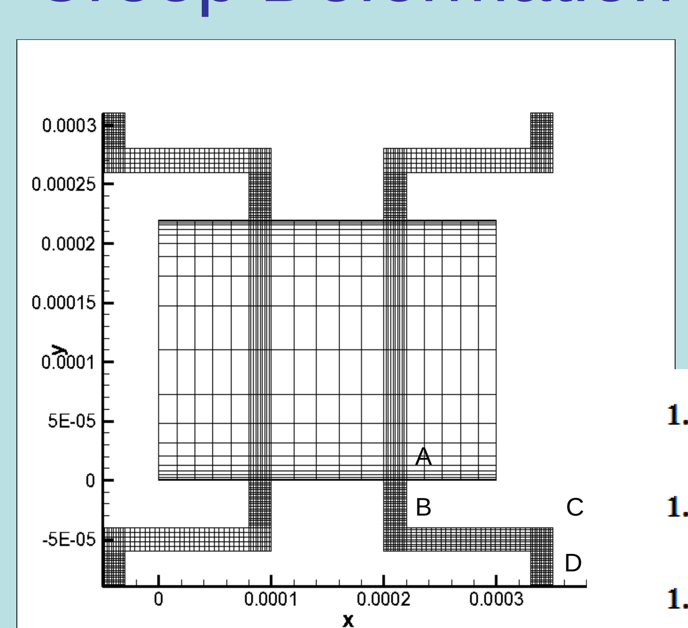
Stresses in the Frogleg Device



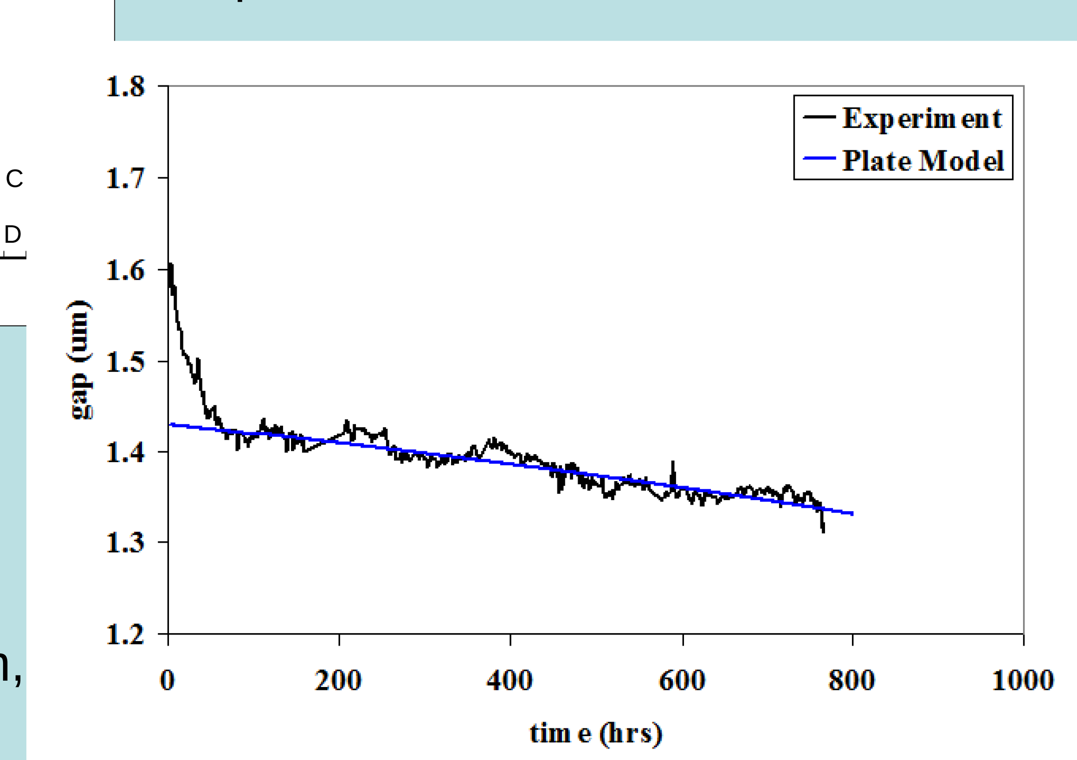
- Stresses mainly carried by the legs of the device
- Stress concentration at the corners
- Simplified beam models insufficient for creep modeling of the device

$$\sum M_x = 0$$
$$\sum M_y = 0$$
$$\sum F_z = 0$$

Creep Deformation in the Frogleg Device



For A = 75x10^{-8}/hr, simulated plate deflection matches well with experimental data



Applied Voltage = 20V

m = 1, n = 0.5, B = 20

$\sigma_{y0} = 0.7GPa$

AB = 40 μm, BC = 90 μm, CD = 30 μm

Conclusions

- FVM solver for creep modeling in RF MEMS has been developed
- The solver models RF MEMS device as a thin plate and uses Mindlin-Reissner plate theory
- The plate model accurately predicts creep in thin RF MEMS devices
- The computation advantage with the plate solver over full 3D FVM structural solver to model long-term creep deformation increases with an increase in aspect ratio
- The solver has been applied to study Coble creep in frogleg RF MEMS device made of nanocrystalline nickel

Future Work

- Extend to PRSIM device creep data
- Extend FVM-based plate model to study deformation of curved RF MEMS devices
- Predict creep in PRISM device for range of voltages

References

[1] S. Das, S.R. Mathur, and J.Y. Murthy, “Finite Volume Method for Structural Analysis of RF MEMS Devices using Theory of Plates,” Numerical Heat Transfer, Part B: Fundamentals, accepted

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