Verification of Plate Model in MEMOSA

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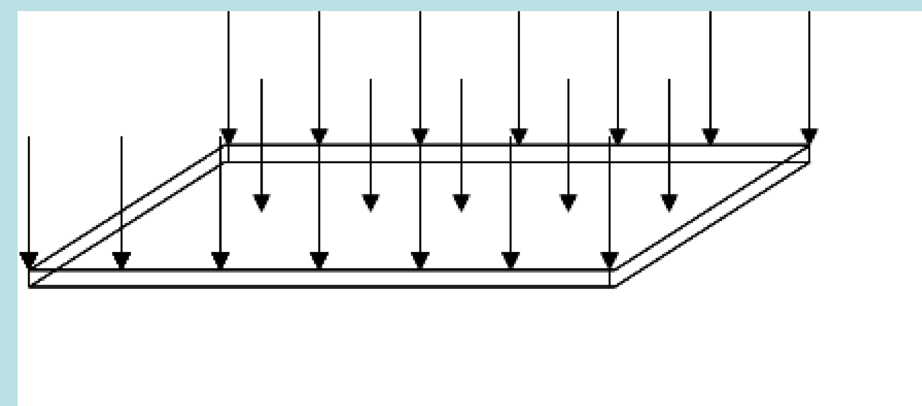
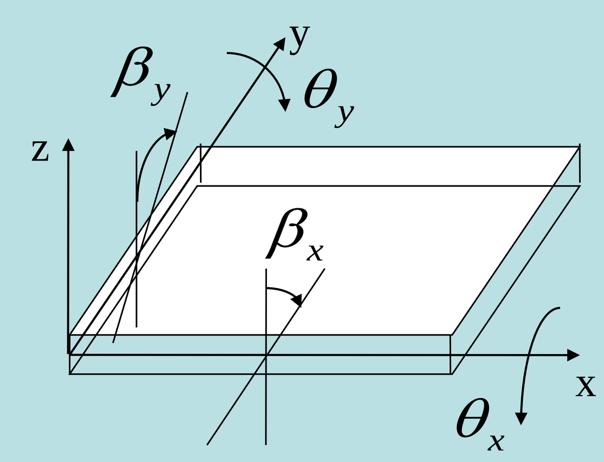
Objective: To Implement FVM-Based Plate Model in MEMOSA Using Mindlin-Reissner Plate Theory

- Implement FVM-based plate model to study deformation of thin membranes
- Use Mindlin-Reissner plate theory
- Implement fully implicit second order discretization of the governing equations
- Verify the accuracy of the solver for a number of canonical test problems
- Verify that locking behavior is not observed for high aspect-ratio structures
- Use the plate model to study pull-in voltages in RF MEMS devices

Plate Model Overview

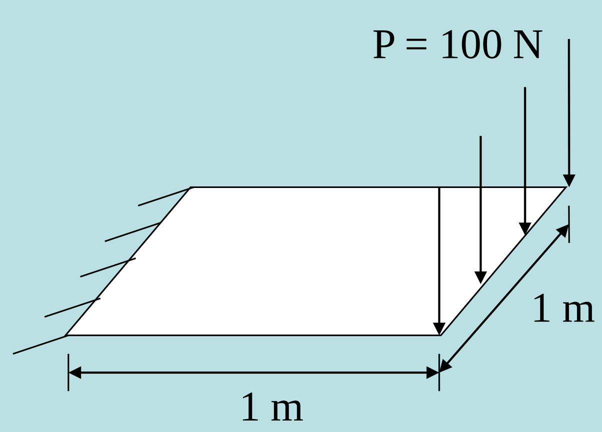


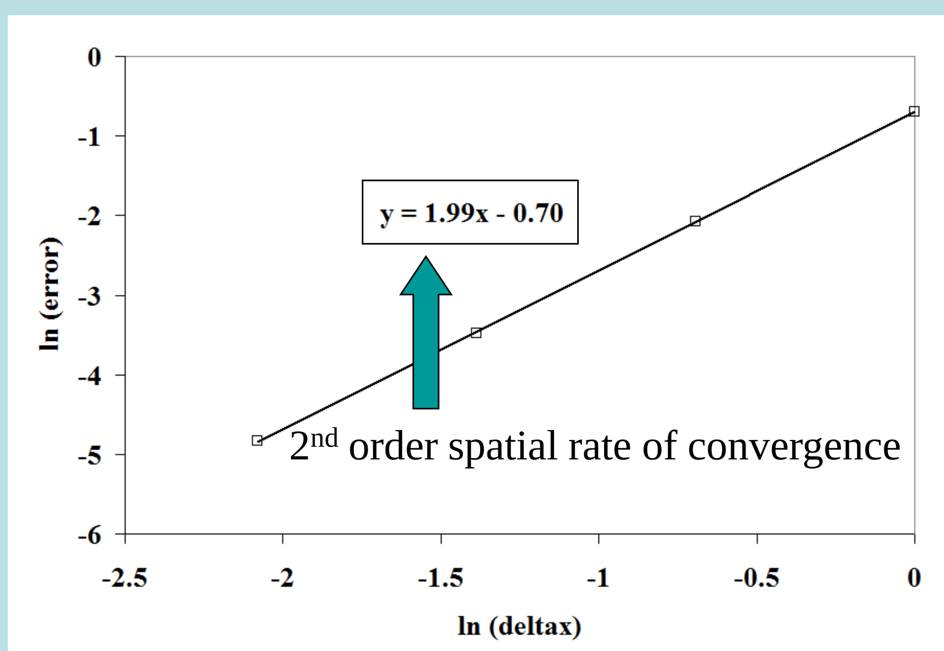


- Solve for vertical deflections and rotations about x and y axes
- Balance moments about x and y axes and force in the z-axis

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

Cantilever Plate



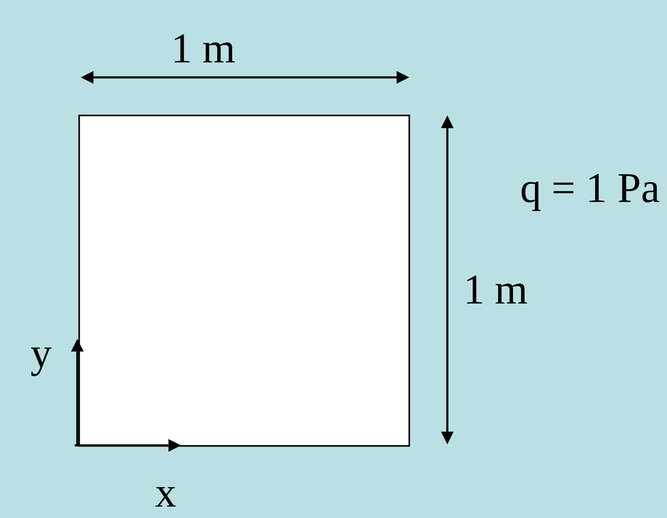


- Plate model accurately predicts deflection at the free end for both thick and thin plates
- Errors decrease by factor of 4 as mesh is refined by factor of 2
- Confirms second order spatial discretization

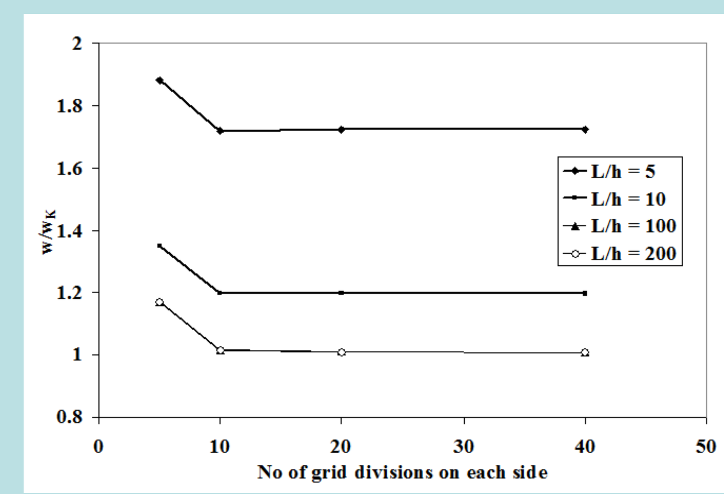
Percentage errors in FVM solution for deflection at the free end of the cantilever plate

Mesh	L/h = 10	L/h = 100
5x5	0.497	0.5
10x10	0.124	0.125
20x20	0.031	0.031
40x40	0.008	0.008

All-Clamped Plate

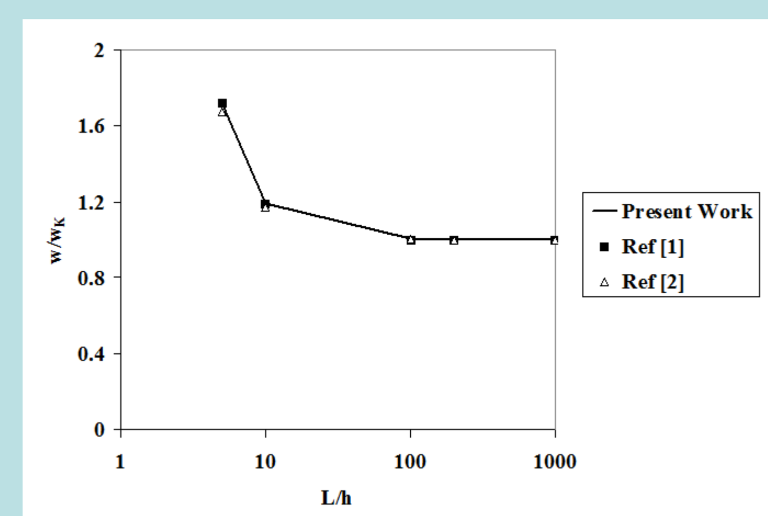


Young's modulus	200 GPa
Poisson's ratio	0.3



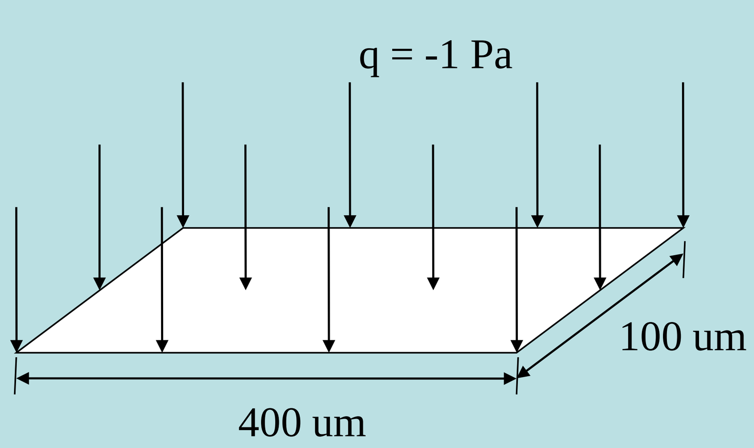
Non-dimensional deflection in the plate

- No locking behavior is observed for high aspect-ratio plates
- Deformation in the plate is accurately predicted over the entire range of aspect ratios



Non-dimensional deflection for 40x40 mesh

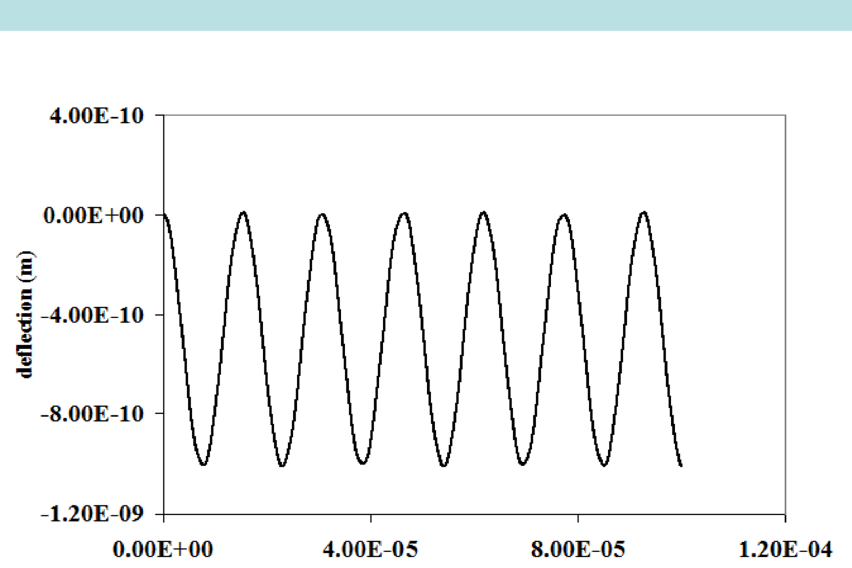
Transient Vibration of Fixed-Fixed Plates



Thickness	2 um
Young's modulus	200 GPa
Poisson's ratio	0
Density	7854 Kg/m^3

	Natural Frequency (Hz)
Analytical	6.497x10^4
FVM	6.485x10^4

Frequency accurately calculated



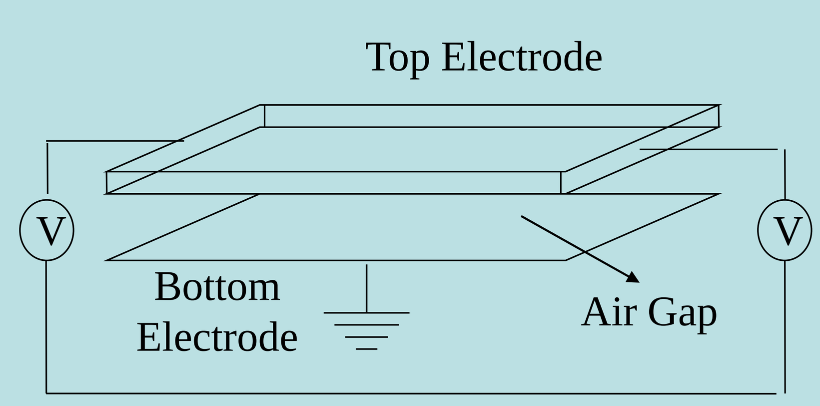
Deflection (x10^{-10} m) vs timestep

Time (us)	Δt (x10^{-9} s)		
	5	2.5	1.25
25	-8.64166	-8.66507	-8.67684

$$p = \left[1/\ln(r_{21})\right]\left[\ln\left|\frac{w_3 - w_2}{w_2 - w_1}\right|\right] = 0.992$$

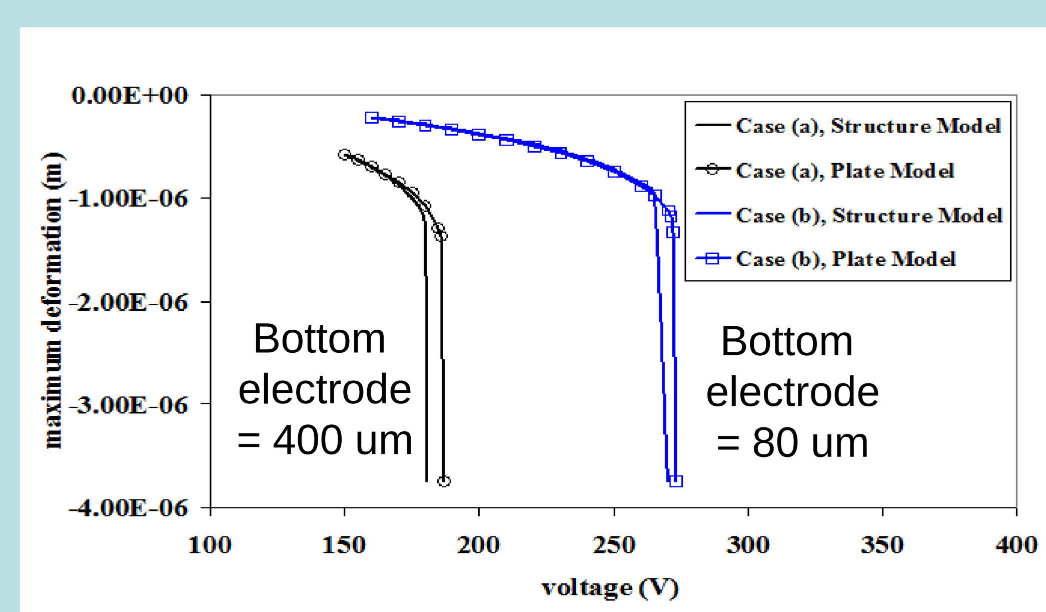
1st order temporal convergence rate

Pull-In Voltage in RF MEMS



Top Electrode details	
Length	400 um
Thickness	4 um
Young's modulus	200 GPa
Poisson's ratio	0
Mesh	40x40

Pull-in voltage computed using plate model is around 3.5% higher than that computed using full 3-D structure model due to absence of non-linear stretching effects



Residual Stress

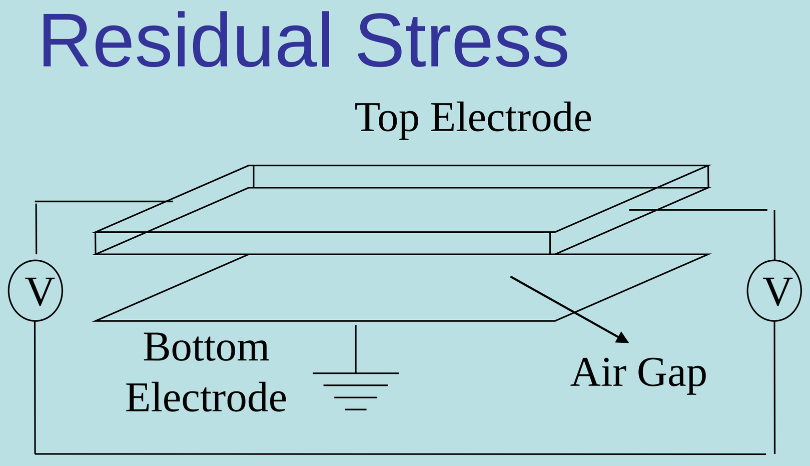


Plate Model accurately predicts deflection in presence of residual stress

Voltage (V)	Residual Stress (MPa)	Deflection at plate center (um)	
		Plate Model	Memshub
100	0	-0.2159	-0.2148
	50	-0.1188	-0.1182
160	0	-0.6903	-0.6868
	50	-0.3348	-0.3332

Conclusions and Future Work

- Fully-implicit Mindlin-Reissner theory based FVM solver for plate bending analysis has been developed
- The solver does not show any instance of shear locking in thin plates
- It has second order spatial rate of convergence and first order temporal rate of convergence
- Residual stress model implemented within the plate model framework
- The solver over-predicts pull-in voltages in RF MEMS devices by around 3.5% due to absence of non-linear stretching effects

PURDUE UNIVERSITY Discovery Park

[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