The Role of Flexural-Slip in the Development of Chevron Folds

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Introduction and Objectives

Chevron folds are special folding phenomena featuring (Figure 1) :
(1) Long straight limbs
(2) Narrow and sharp hinges
(3) Hinge collapse (some folds)

Common hypotheses to form chevron folds:

(1) Material anisotropy:

Effective anisotropic viscosity

$N=\mu_1\alpha_1+\mu_2\alpha_2$

$Q=1/(\mu_1/\alpha_1+\mu_2/\alpha_2)$

$A=N/Q$

N: normal stress
Q: shear stress
A: degree of anisotropy
μ: layer's viscosity
α: fractional thickness

(2) Flexural-slip:

No viscosity contrast ('effective single layer')
Distribution of amount of slip variable
- Maximum value — Inflection point
- Zero — Hinge zone

Some sublayers remain welded together
Time of slip initiation / occurrence
- Chevron folds: Later stages (Bastida et al., 2007)
- General buckle folds: Early stages (Damasceno et al., 2017)

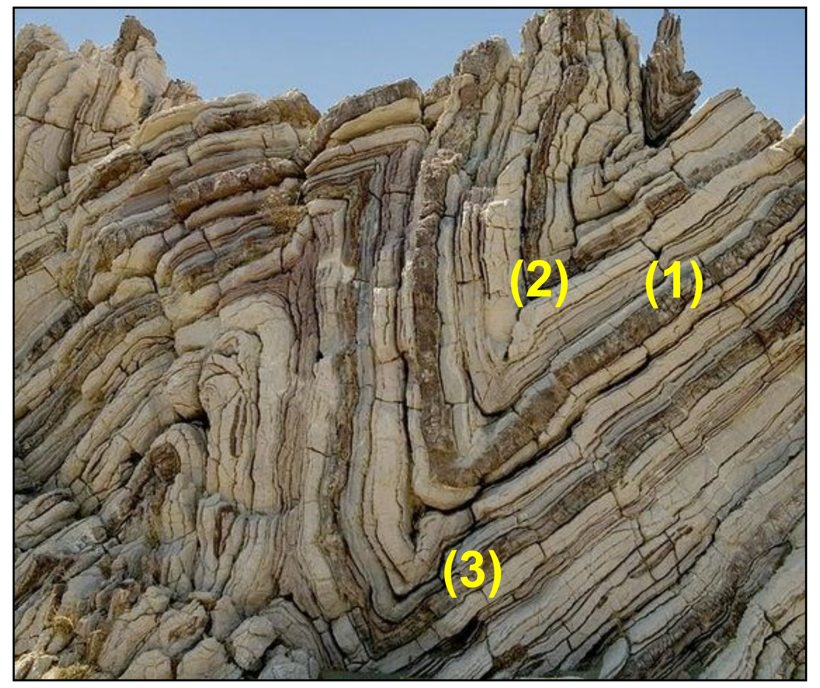


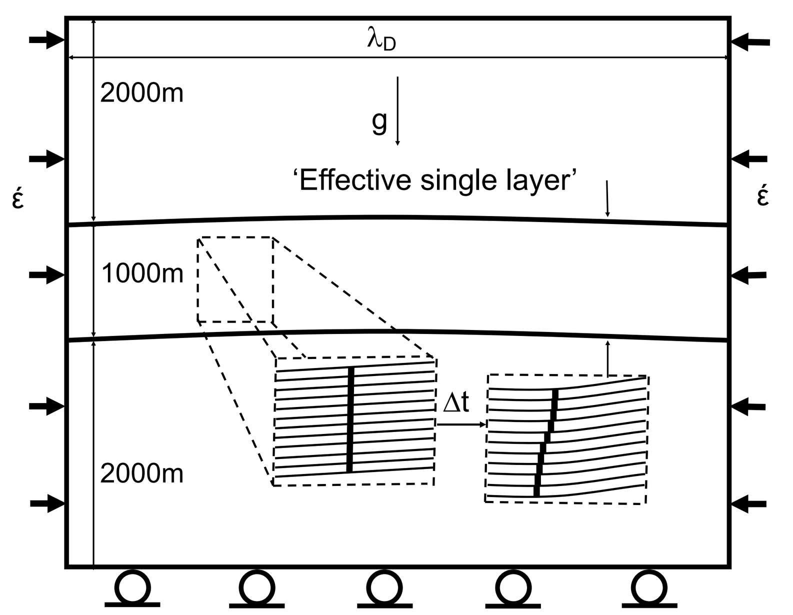
Figure 1. Multilayer-chevron folds with hinge collapse in the Agios Pavlos Area in Rethymnon, in south central Crete.

Objectives:

Investigate the conditions and folding mechanisms for chevron folds to form.
Quantify the slip evolution during chevron folding.

Methodology: 2D Finite Element Analysis

Model Setup:



Model Features:
- 20 sublayers separated by frictional interfaces
- Maxwell viscoelastic rheology
- Gravitational pre-stressing
- Initial hydrostatic pore pressure
- 50% of horizontal shortening applied using strain rate of 10^{-14} s^{-1}
- Various initial perturbations

Sensitivity analyses:

Parameter	Values
Initial perturbation	Sinusoidal, White noise
Initial perturbation wavelength	$0.1\lambda_D$, $0.5\lambda_D$, $1\lambda_D$ *λ_D-dominant wavelength
Friction coefficient (μ)	0.2, 0.6

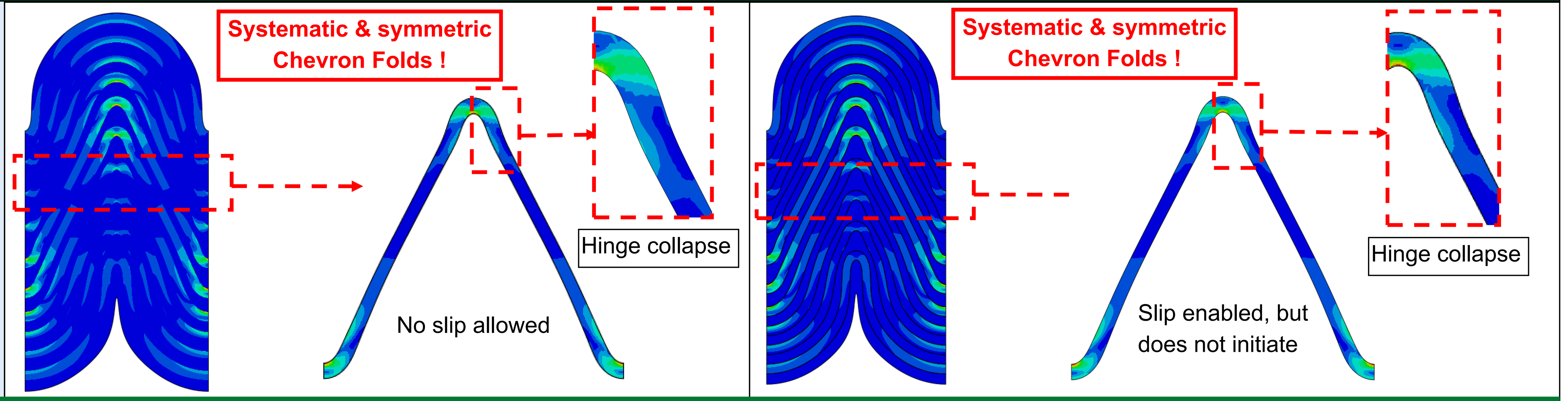
Material properties:

Properties	Folding layer	Matrix
Specific gravity	2.30	2.30
Viscosity (Pa s)	5×10^{21}	5×10^{19}
Young's modulus (GPa)	30	3
Poisson's ratio	0.25	0.25
Porosity	0.20	0.20
Permeability (m^2)	5×10^{10}	5×10^{10}
Friction coefficient	0.60	0.60

Results

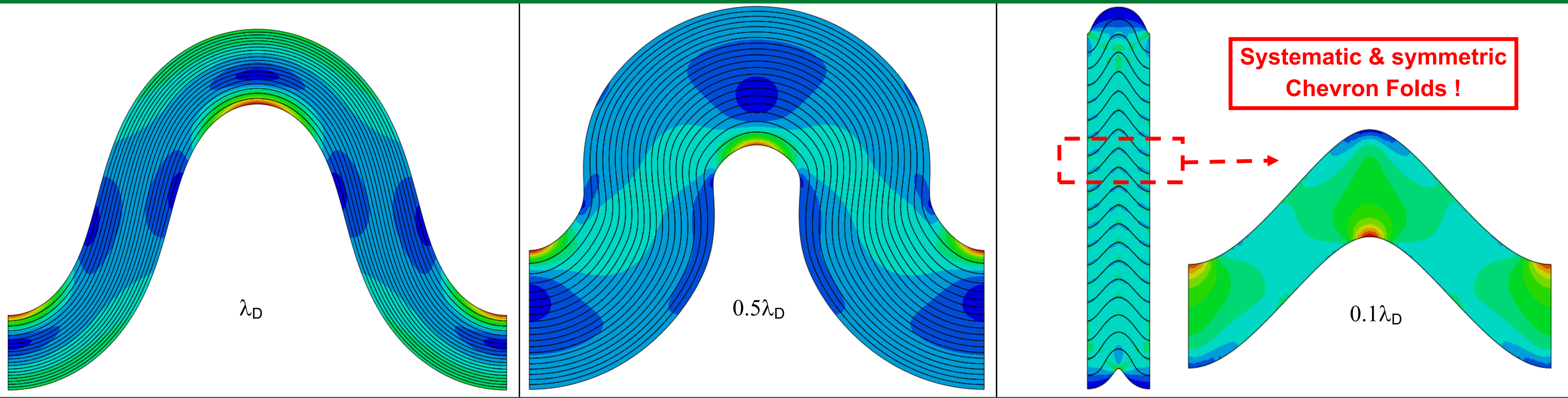
Series #1:
- Sinusoidal initial perturbation: λ_D
- Anisotropic folding layers, i.e. true multilayer
- With / without slip

Results:
- Systematic & symmetric chevron folds with hinge collapse.
- Flexural-slip can not change folding shape in true multilayers model



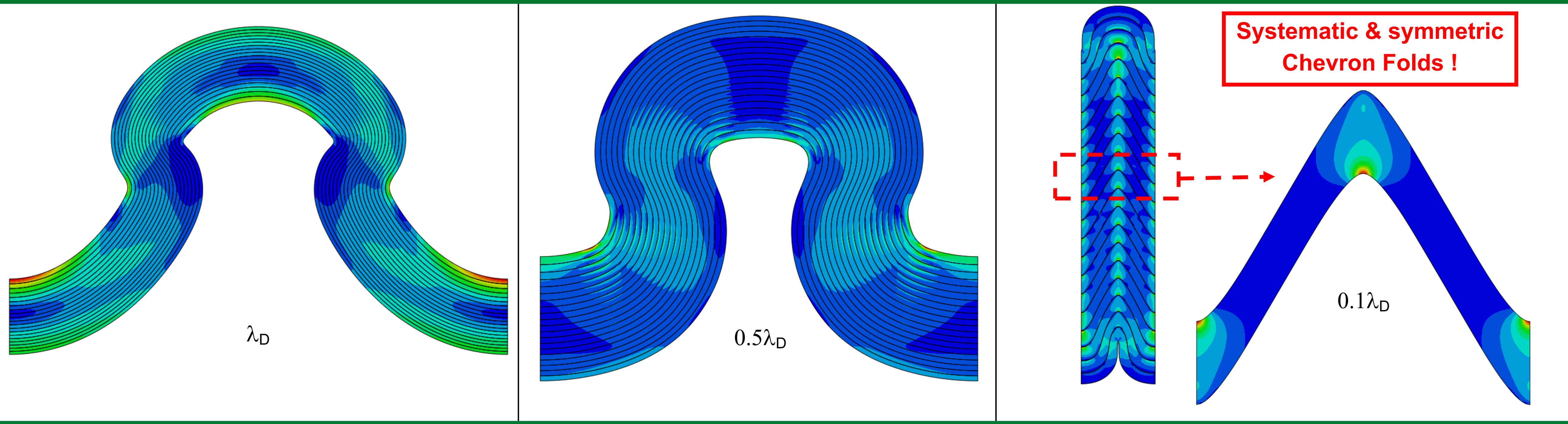
Series #2:
- Sinusoidal initial perturbation: $\lambda=\lambda_D$, $0.5\lambda_D$, $0.1\lambda_D$
- 'Effective single layer' with slip
- High friction coefficient (μ=0.6)

Results:
- 10% of dominant wavelength with μ =0.6 produces chevron folds with out hinge collapse.



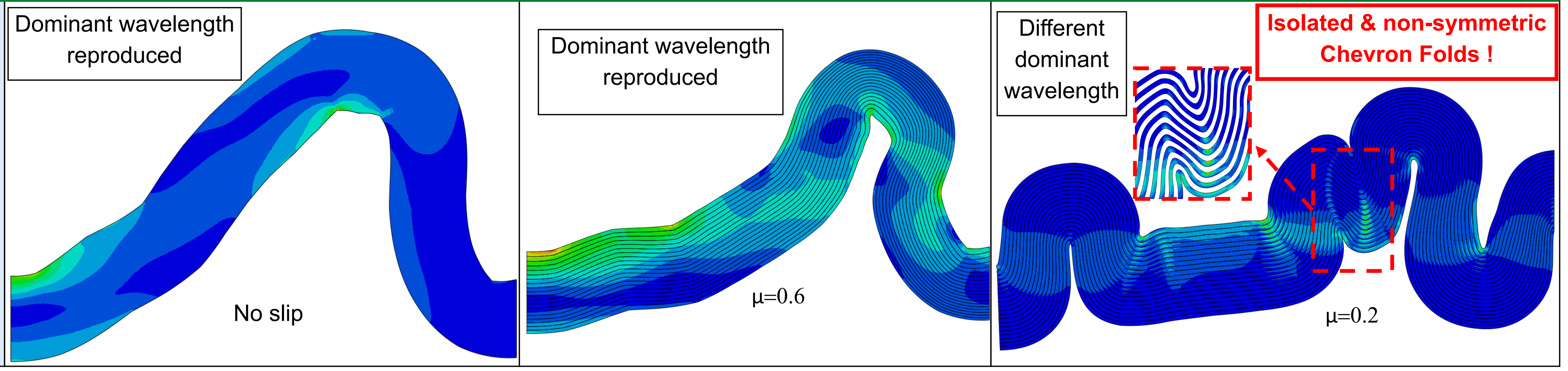
Series #3:
- Sinusoidal initial perturbation $\lambda=\lambda_D$, $0.5\lambda_D$, $0.1\lambda_D$
- 'Effective single layer' with slip
- Low friction coefficient (μ=0.2)

Results:
- 10% of dominant wavelength with μ =0.2 produces chevron folds with-out hinge collapse.
- Chevron folds: larger amplitudes & shaper inter-limb angle compared to Series #2.



Series #4:
- White noise initial perturbation
- True multilayer setup/effective single layer
- High / low friction coefficient (μ=0.2 / 0.6)

Results:
- Non-symmetric chevron folds are generated when lower friction coefficient is applied.



Discussion

The slip tendency parameter is chosen to indicate the temporal evolution of slip. Slip tendency, Ω,is defined by:

$$\Omega=\frac{\sigma_n}{\mu\sigma_s}$$

σ_n: normal stress;
μ: friction coefficient;
σ_s: shear stress;

For Ω=1 slip occurs.

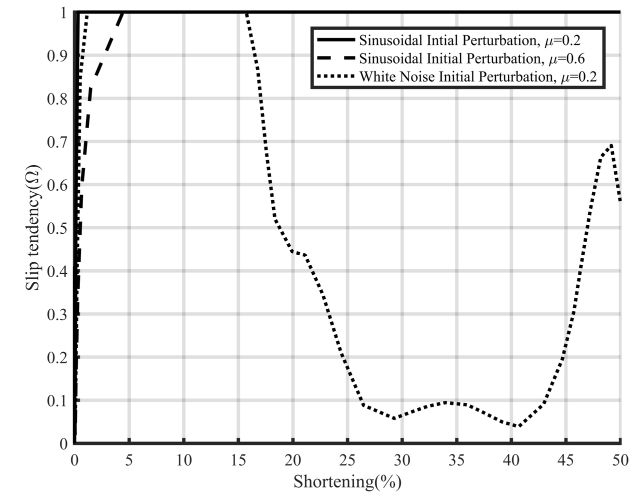


Figure 2. Slip tendency of chevron folding model in Series#2, #3, #4.

- For all chevron folds models, slip is initiated at the early stages of folding, i.e. ~1% - ~5% of shortening. This is in contrast to field observations of chevron folds (Bastida et al., 2007) where slip is observed during the later stages of folding.
- The initial perturbation affects slip occurrence:
  - For sinusoidal perturbations slip occurs throughout 50% of shortening
  - For the white noise perturbations, slip is initiated later and ceases after ~16% of shortening.

Conclusions

1. Systematic, symmetric chevron folds are generated by:
   - flexural flow folding of anisotropic layers
   - flexural-slip folding with 10% of dominant wavelength

   Only flexural flow folding with anisotropic layers produces the hinge collapse in the incompetent layers.
   Chevron folds are generated during early stages of slip initiation.
2. Non-systematic, isolated chevron folds are generated by:
   - flexural-slip folding using white noise initial perturbations

   By reducing the friction coefficient, thinner limbs, sharper inter-limb angles and higher amplitude chevron folds are generated.

Outlook

1. According to Series #4, the relationship between friction coefficient and dominant wavelength needs to be expressed quantitatively.
2. Investigate the discrepancy of timing of slip during chevron folding: Early slip observed in this study vs. slip initiated during later stages (Bastida et al., 2007).

References

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