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Evaluation of Interface Reductions for Craig Bampton Substructured Models

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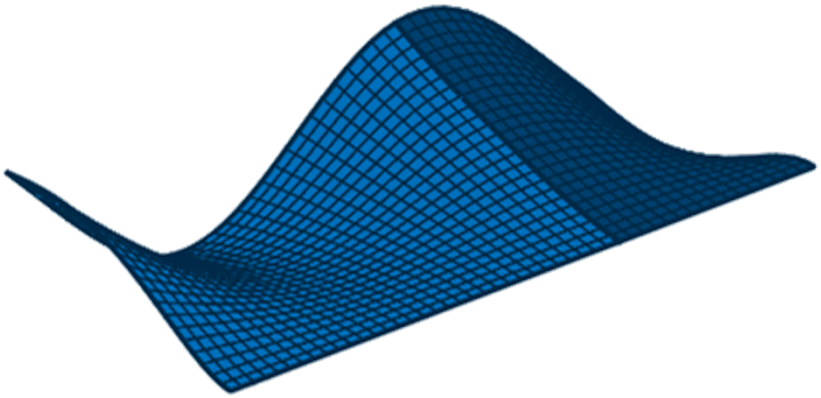

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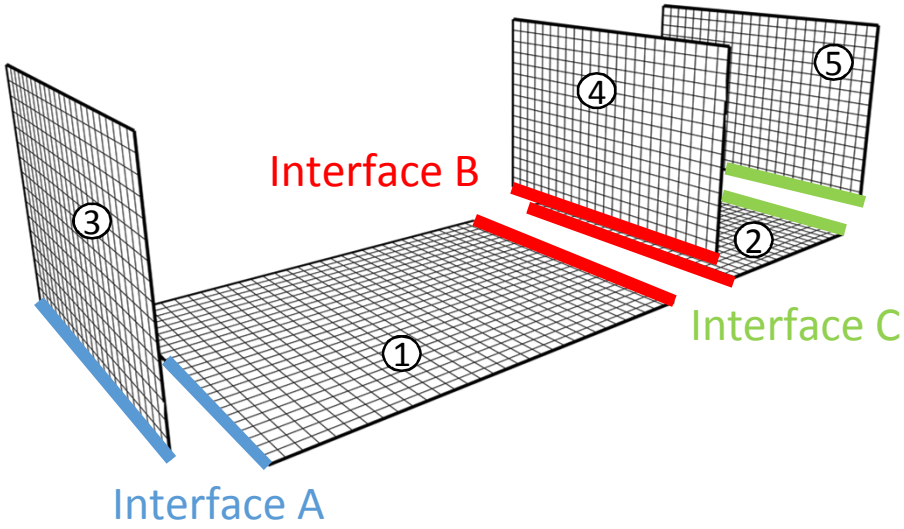
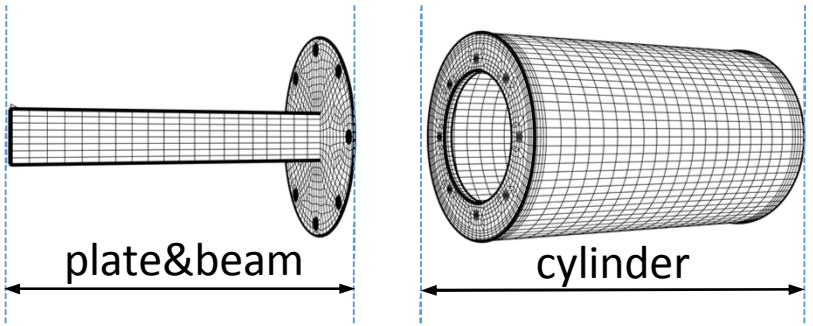
Introduction

- The Craig-Bampton (CB) approach can be used to assemble substructures into a reduced order system model but all physical degrees of freedom at the substructure interfaces are retained, which can lead to unacceptably large equations of motion
- 5 different interface reduction techniques for reducing the interface degrees of freedom are evaluated
  - System characteristic constraint (S-CC)
  - Exact compatibility local characteristic constraint (L-CC)
  - Weak compatibility L-CC
  - Hybrid characteristic constraint (H-CC)
  - Undeformed interface method (UIM)

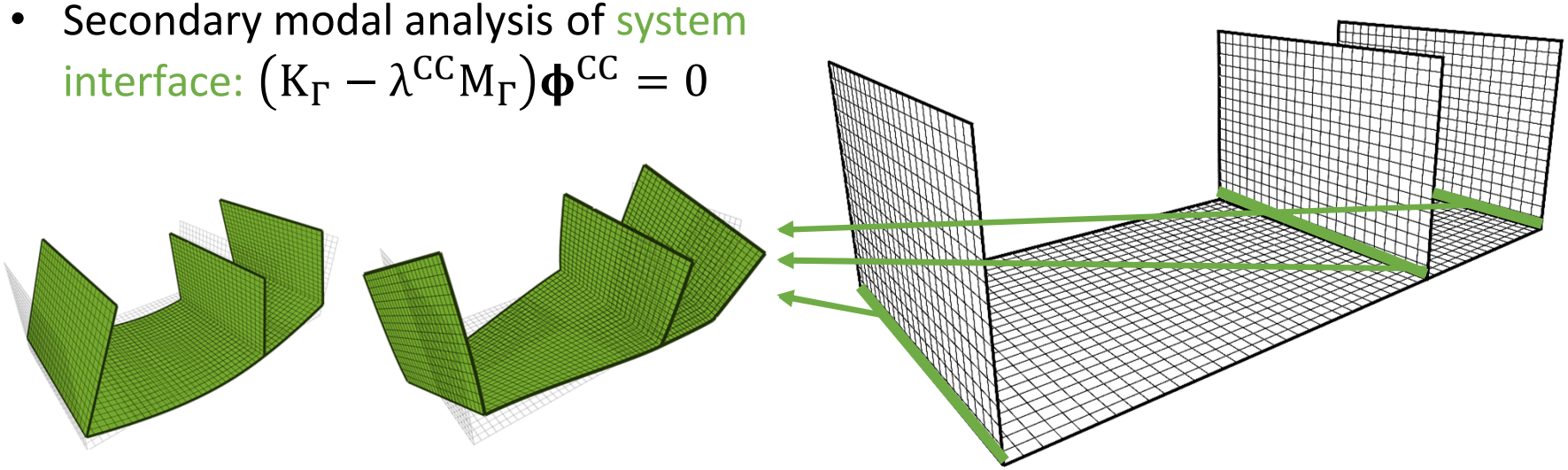
Finite Element Models





Method: S-CC [2]

- Secondary modal analysis of system interface: $\left(\mathrm{K}_\Gamma - \lambda^{\mathrm{CC}}\mathrm{M}_\Gamma\right)\boldsymbol{\Phi}^{\mathrm{CC}} = 0$

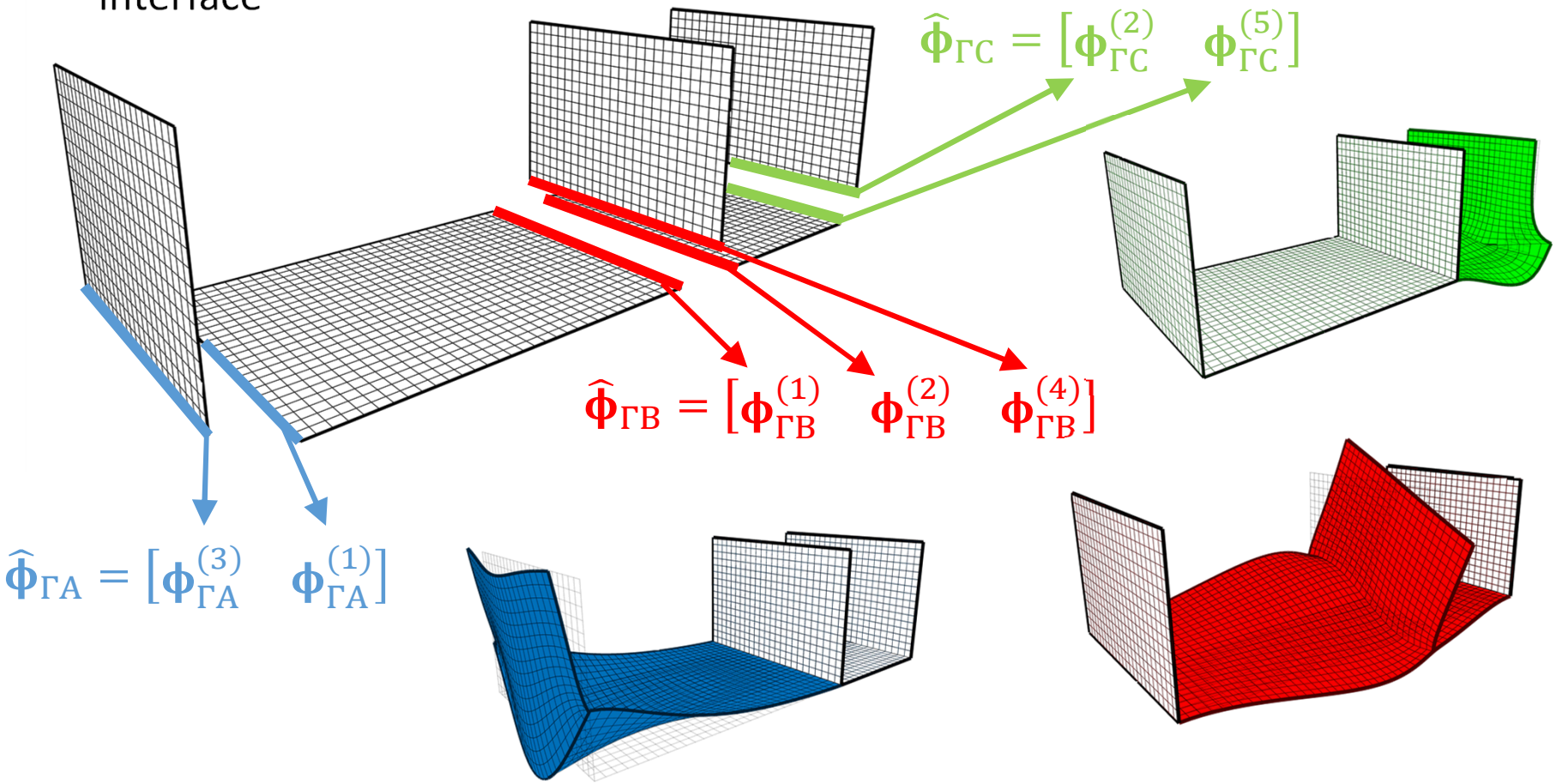


Example characteristic constraint mode shapes

- Interface eigenvectors are truncated and used as a reduced basis for the interface $\rightarrow \widehat{\boldsymbol{\Phi}}^{\mathrm{CC}}$

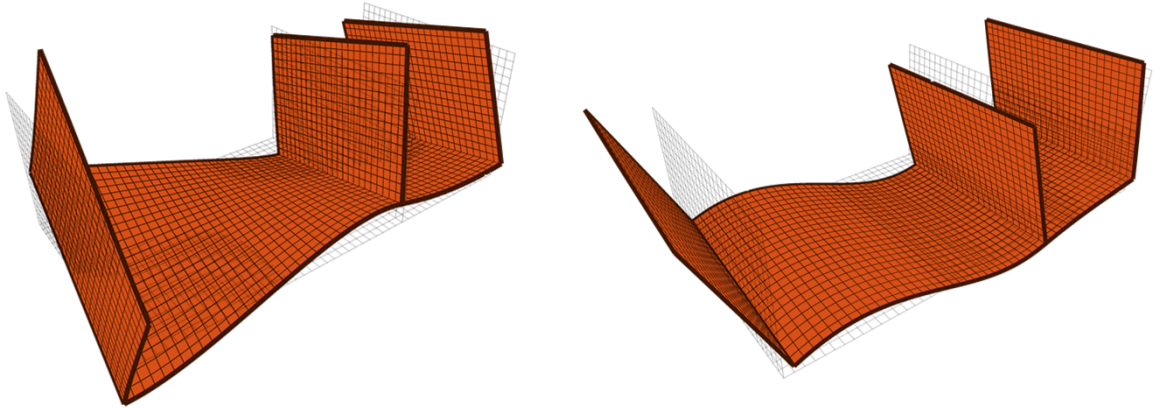
Method: Exact-Compatibility L-CC [3]

- Collect modes for each interface set from all connected substructures
- Combined mode set is orthogonalized and then used as a basis for that interface



Method: Weak-Compatibility L-CC [4]

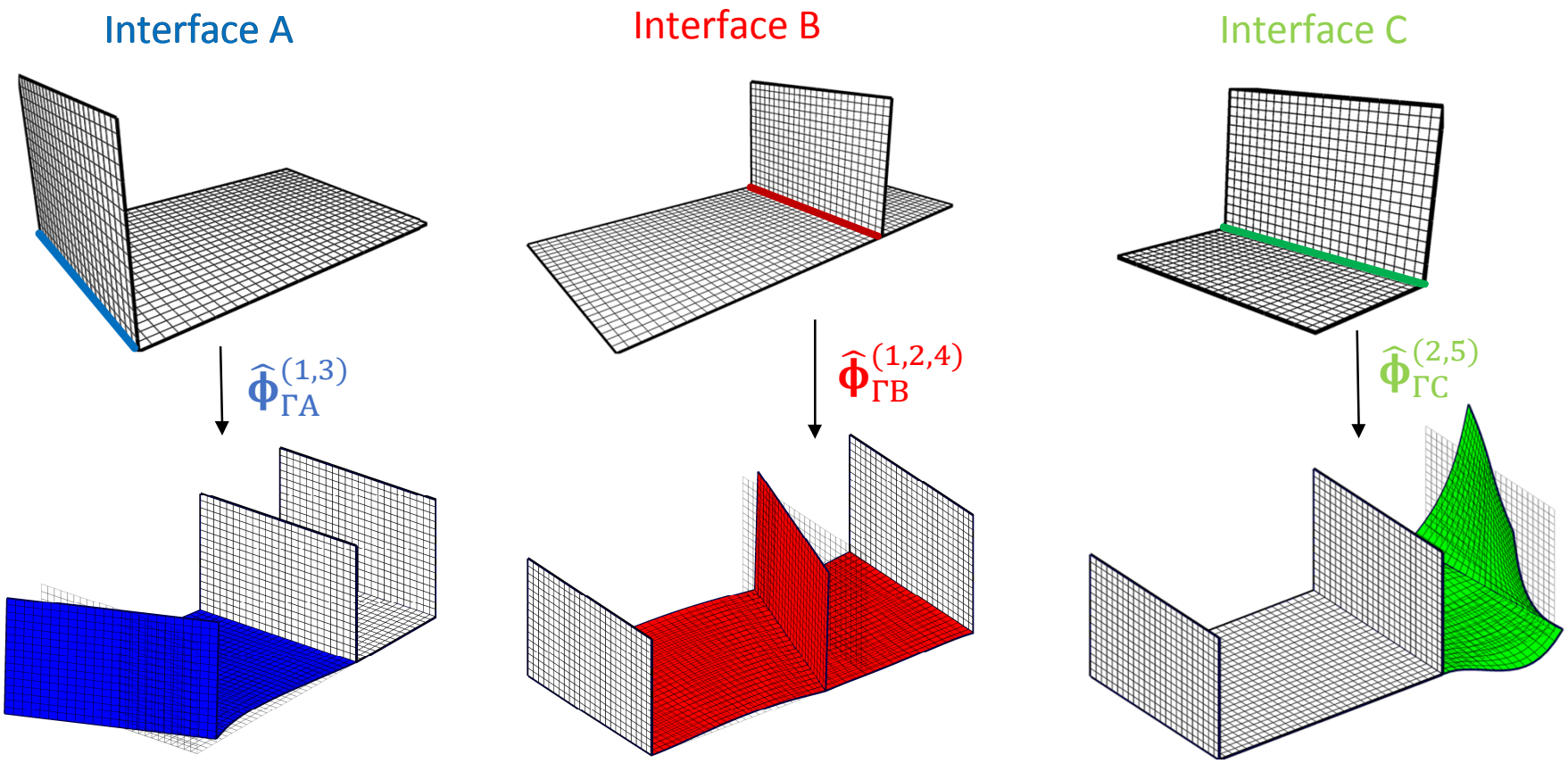
- Each substructure's interface is reduced by a set of its own interface modes (i.e. not a combined set)
- Weak compatibility is enforced by linking a linear combination of interface modes from one substructure to a linear combination of interface modes from a neighboring substructure.



Example interface modes after weak-compatibility enforcement

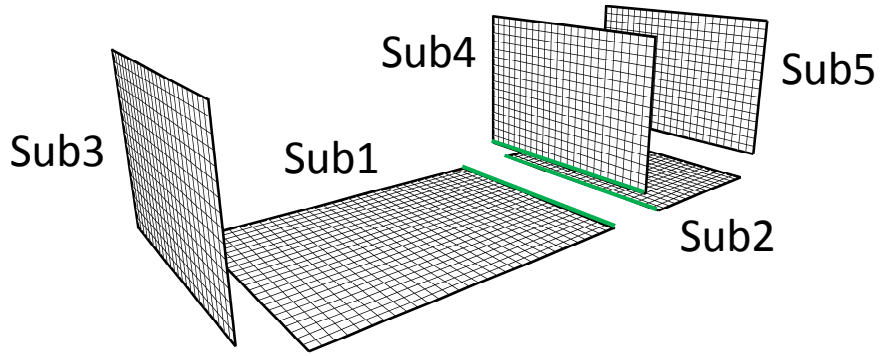
Method: H-CC

- A secondary eigenvalue analysis is performed at the interface partitions of the assembled stiffness and mass matrices among localized substructures sharing the same interface
- This technique is a combination of the S-CC and L-CC approach to keep good accuracy and localize the eigenvalue analysis for each interface

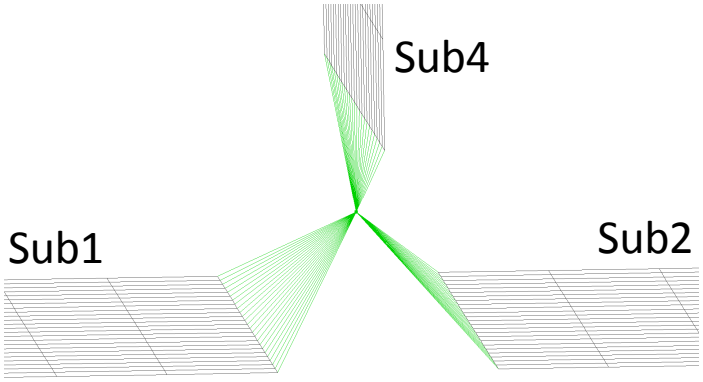


Method: Undeformed Interface

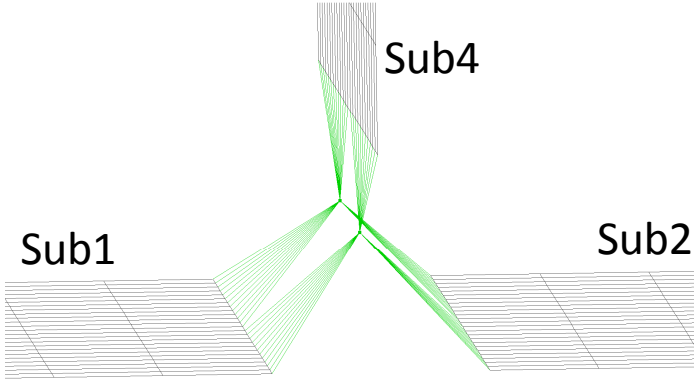
- Each interface node is tied to one of *n* virtual nodes
- Each virtual node is represented by three rigid translations and rotations, that retain an undeformed interface shape



1 virtual node



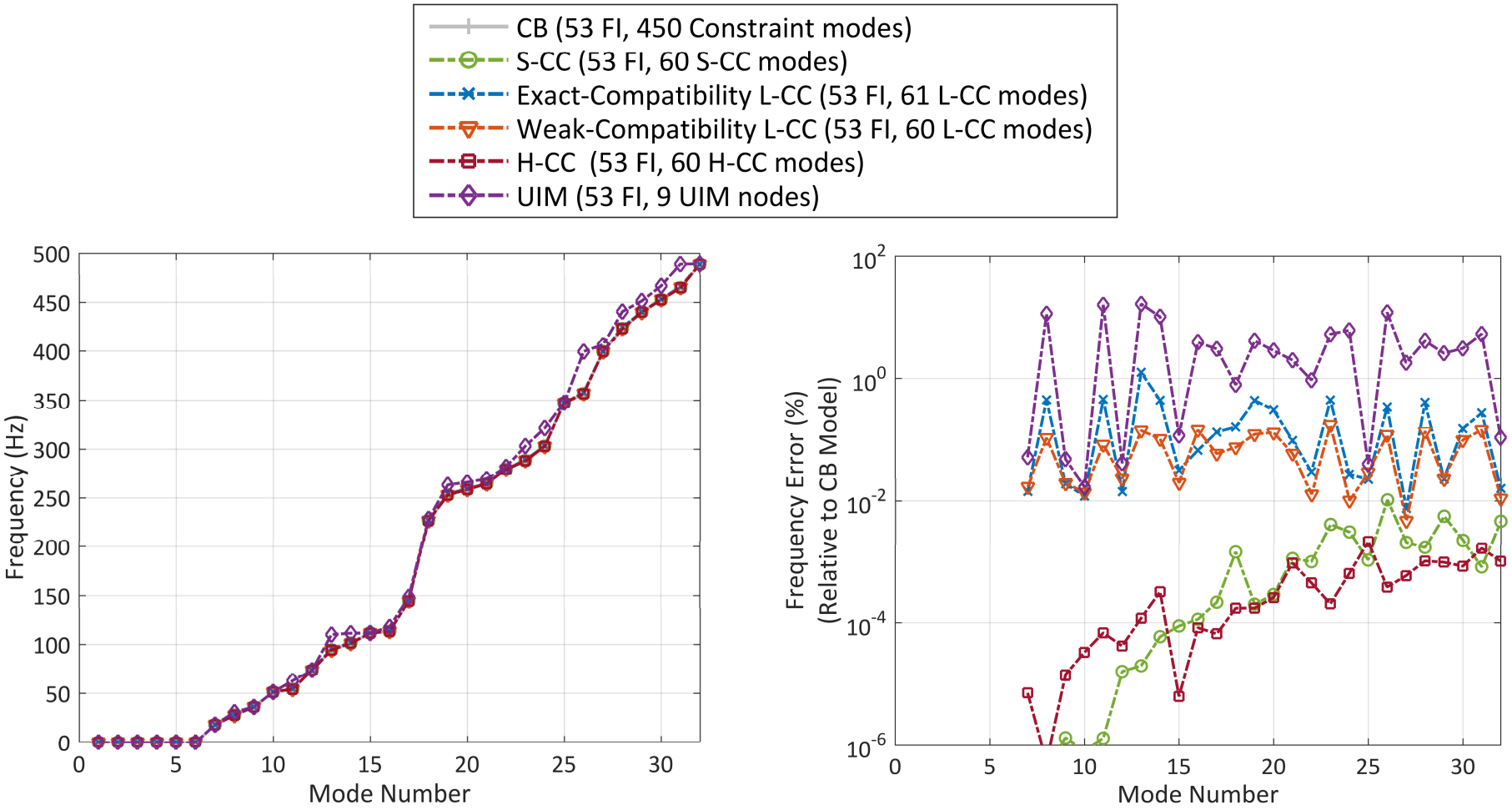
2 virtual nodes



Method: Mode Selection

- The choice of CC modes forming the interface reduction basis influences the reduced model's accuracy
- Influence factors: selected CC modes & number of CC modes
- Mode selection criterions:
  - Frequency cutoff rule (FC)
  - Modified Effective Interface Mass (EIM) [7]
  - Coupling matrix based (CMSχ) [8]

Results: Frequency Comparison

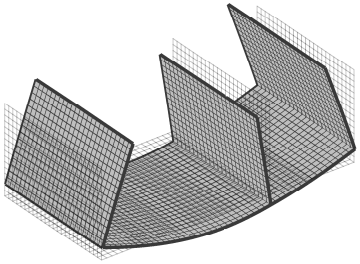


Frequencies and corresponding relative error comparison for different interface reduction techniques

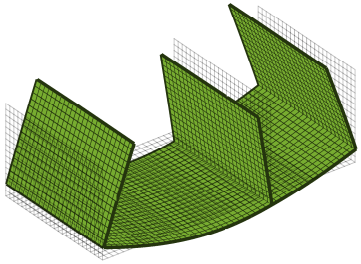
Results: Mode Comparison

7^{th} mode

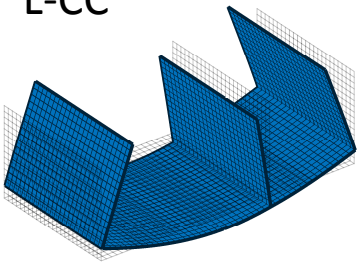
CB method (reference)



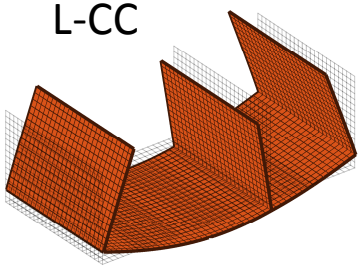
S-CC



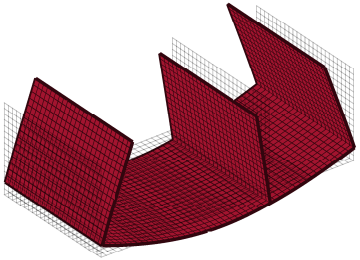
Exact-Compatibility L-CC



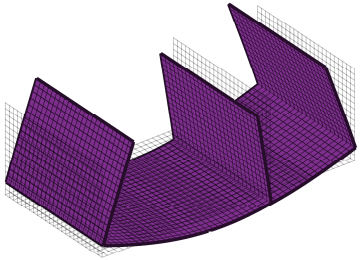
Weak-Compatibility L-CC

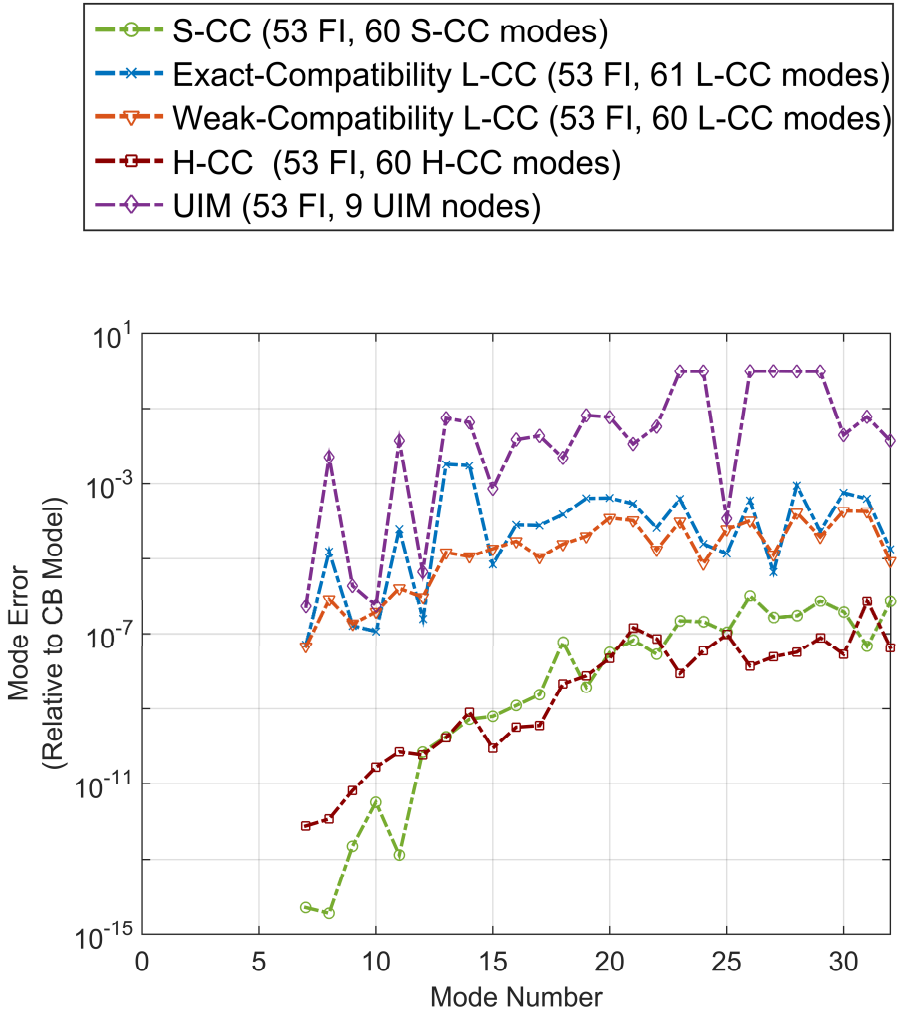


H-CC



UIM





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