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IMAC XXXVI
Predicting Assembly Effective Mass from Two Component Effective Mass Models

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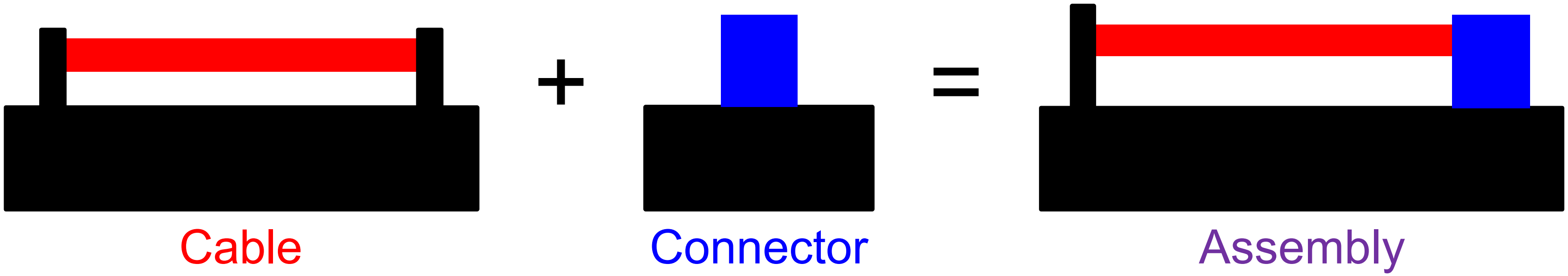
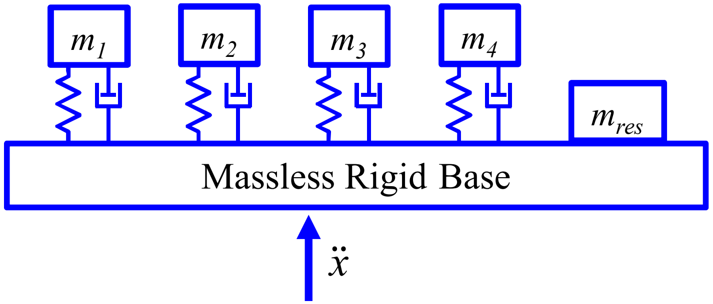
Motivation

- This work focuses on the development of an effective mass modal model of a cable-connector assembly for the purposes of margin quantification
- Developing effective mass modal models of cable-connector assemblies poses several challenges
  - Finite element models (FEMs) typically not developed
  - Multiple cable-connector combinations make analytical modeling and explicit testing of each combination impractical
- **The goal of this work is to develop a method to predict the effective mass and natural frequencies of the cable-connector assembly using limited dynamic information from its components**



Effective Mass

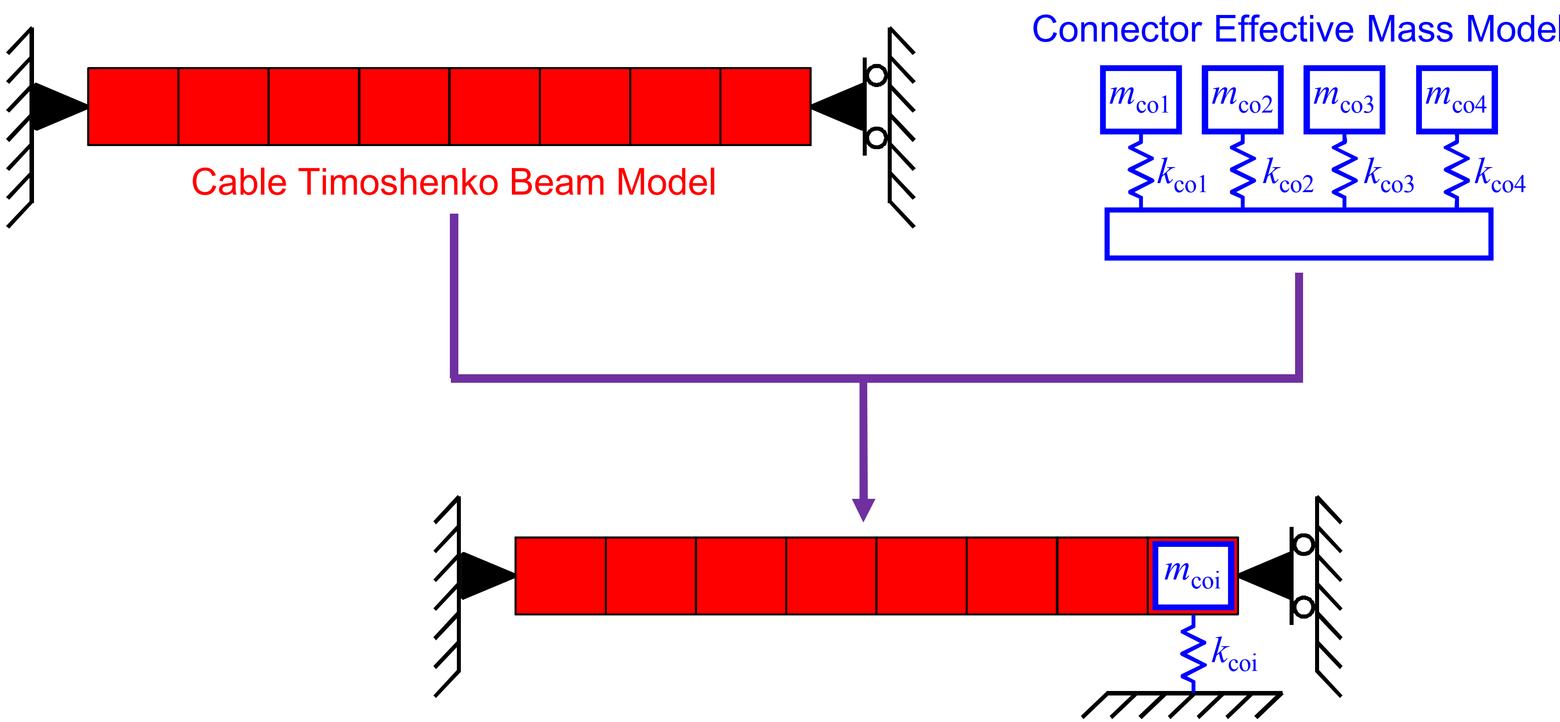
- An effective mass model is a modal model that simulates the response of a component due to a base acceleration input in one direction



- It can be used to calculate the actual energy in the component during the base acceleration environment
  - Useful metric for comparing energy at failure compared to energy in a qualification test (margin)
- Effective mass models can be computed from a FEM or extracted from a modal test of a component on a fixture
- Typically there are three effective mass modal models for a component, one for each of the X, Y, and Z translational directions
  - Normally rotational directions are ignored, since standard vibration table tests are usually focused in one translational direction

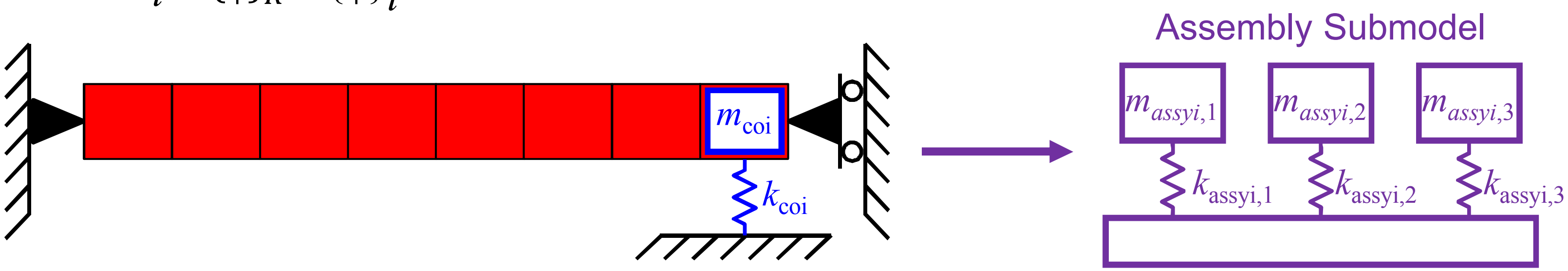
Proposed Method

- Create simple numerical Timoshenko beam model for Cable using desired length and stiffness properties (fit from experimental data)
- Extract an effective mass modal model of the Connector from modal test
- Connect an individual Connector effective mass and stiffness to the tip of the Cable



Proposed Method

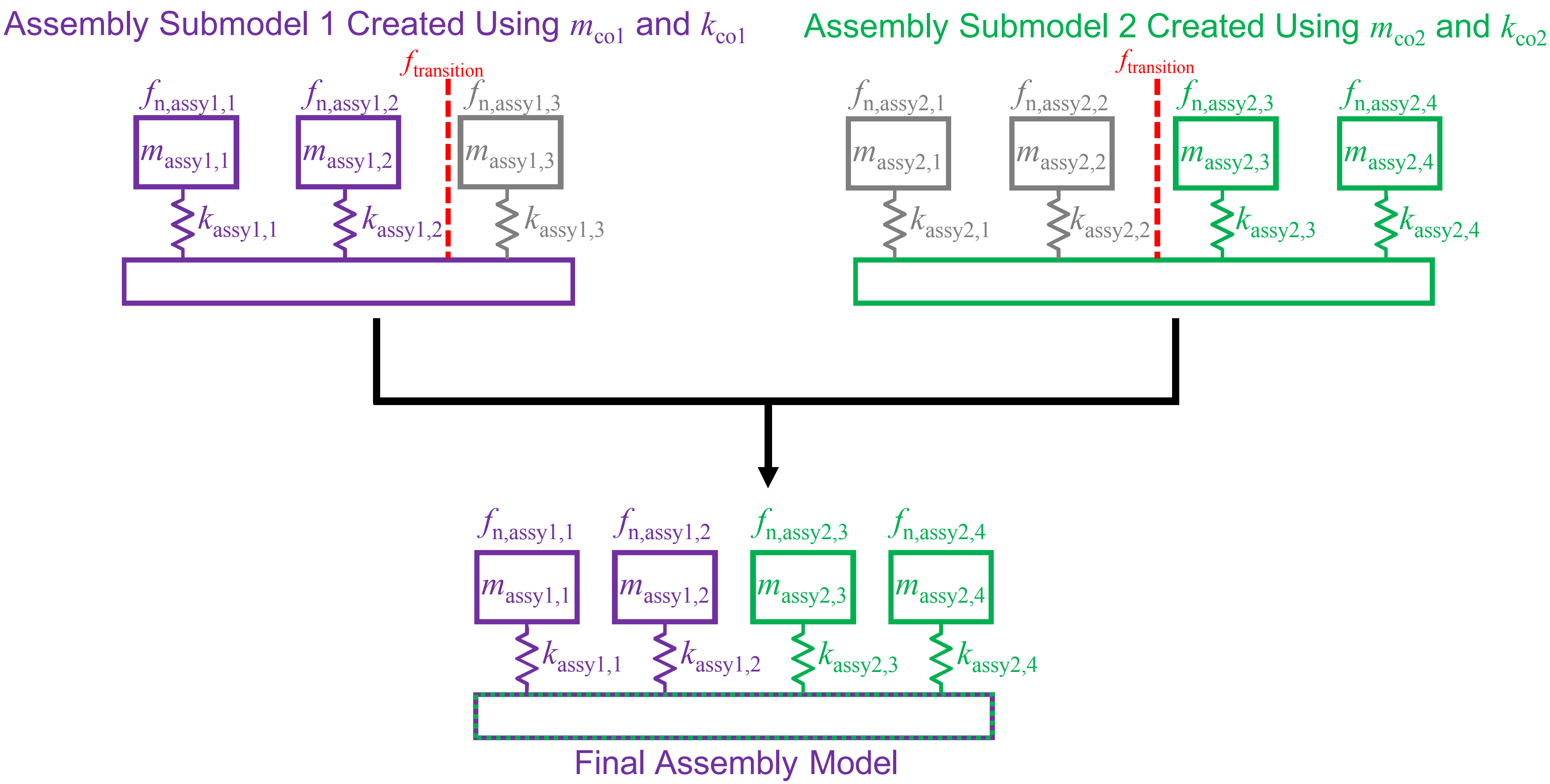
- Compute the effective mass model of this assembly to produce an Assembly Submodel using:
  - $m_i = P_i^2$
  - $P_i = \{\phi\}_R \mathbf{M} \{\phi\}_i$



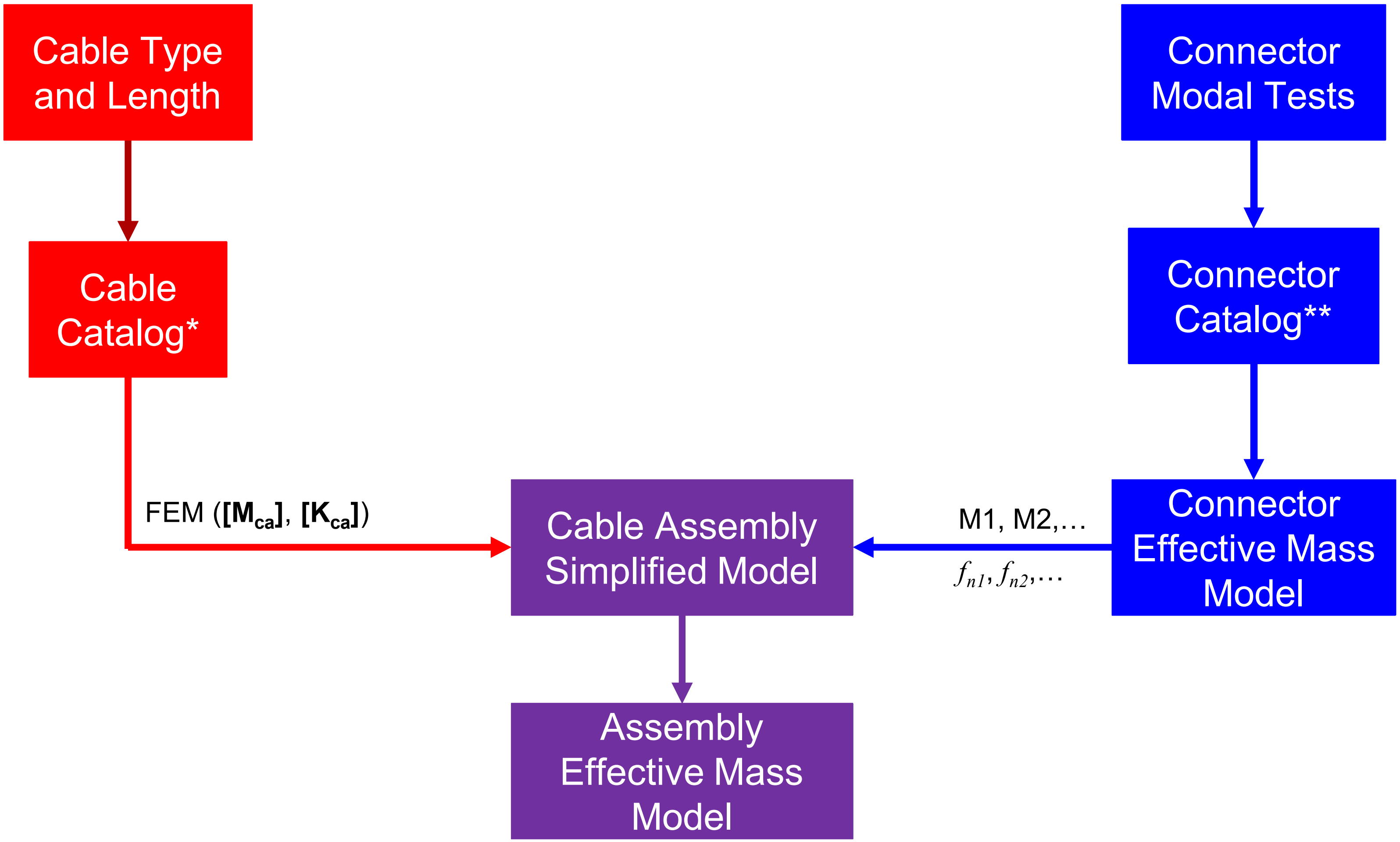
- Repeat this process with the next Connector effective mass and stiffness to create many Assembly Submodels
- Only connector modes with large m_{coi} are used in this process so that the cable tip is loaded as it is in the assembly
  - A connector mode with very small effective mass would essentially produce an assembly submodel of a pin-free cable which does not accurately represent the physical cable-connecter assembly

Proposed Method

- Arrange Assembly Submodels to create the final effective mass modal model of the cable-connector assembly (Final Assembly Model)
  - Only modes within a specific bandwidth are kept from each Assembly Submodel



Practical Implementation

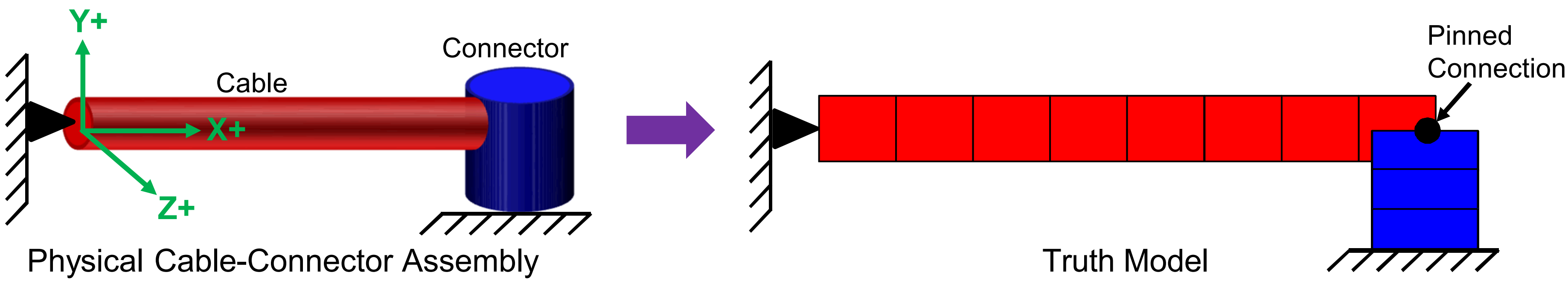


*Catalog consists of EI and KAG values empirically derived from modal tests on different cable types and lengths

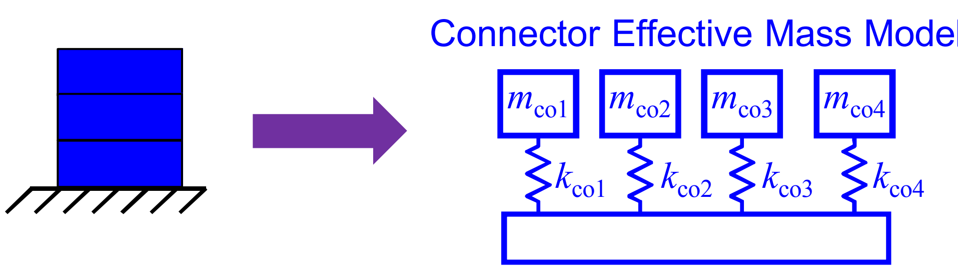
**Catalog consists of modal test results from various connector types

Analytical Verification

- Analytical truth model created to investigate the efficacy of the proposed method
  - Cable was modeled as a Bernoulli-Euler beam
  - Connector represented by cantilevered beam



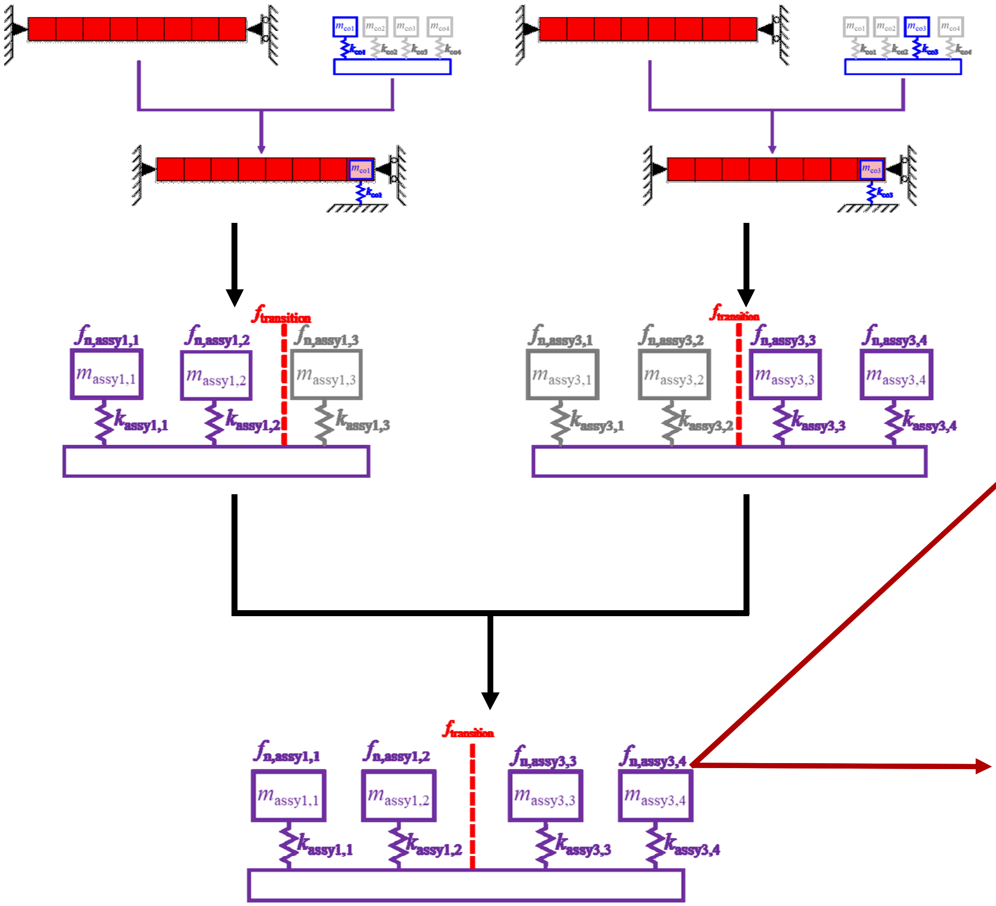
- The effective mass model of the connector was derived from the cantilevered beam used in the truth model

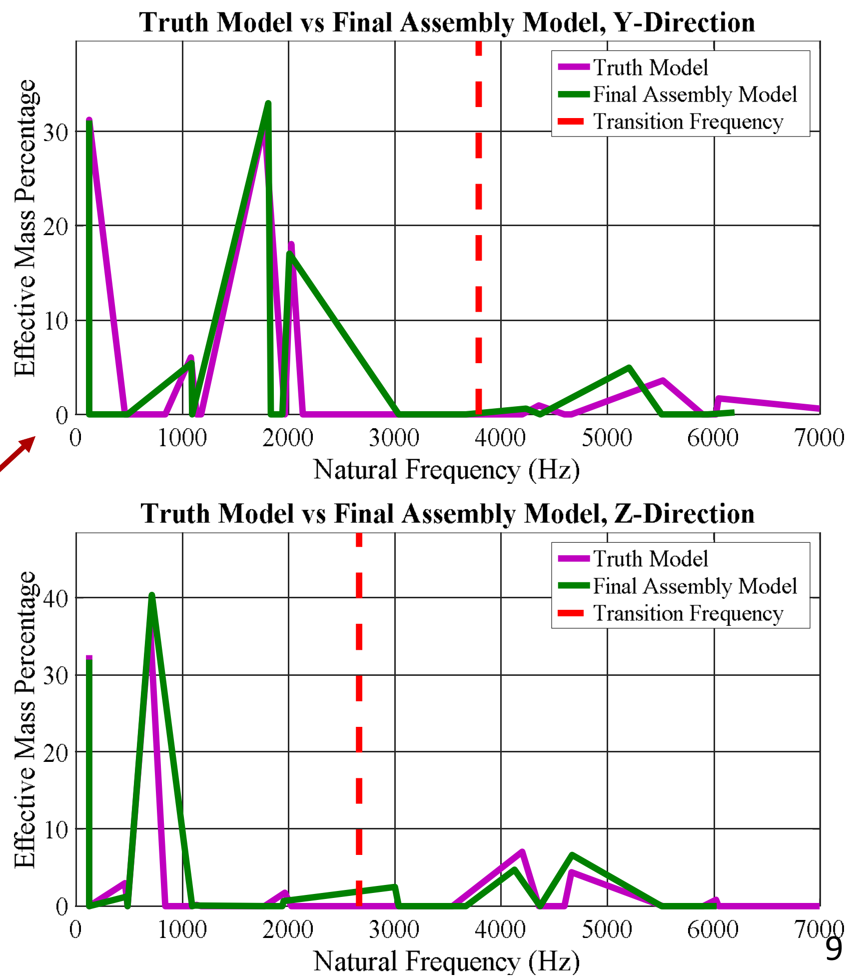


- The focus of this work is on the transverse directions of the cable (Y and Z) as X direction frequencies and effective mass were determined by a different method

Analytical Verification Results

- For each direction, there were two connector modes with large effective mass below 7000 Hz, so there is one transition frequency





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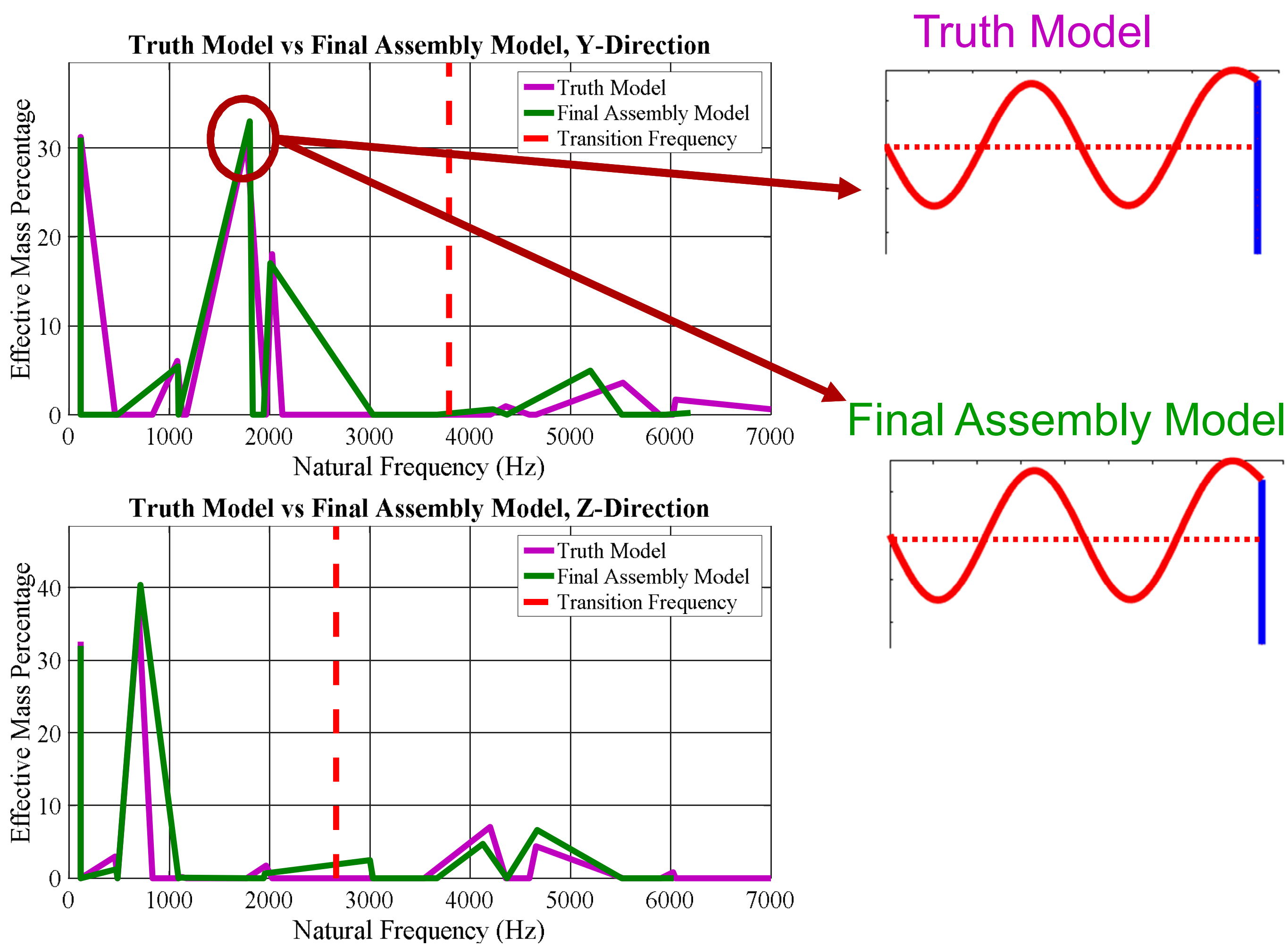

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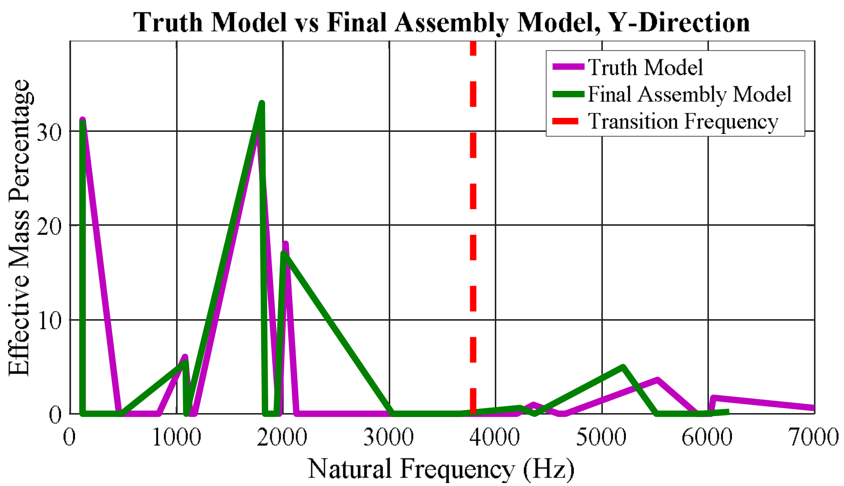
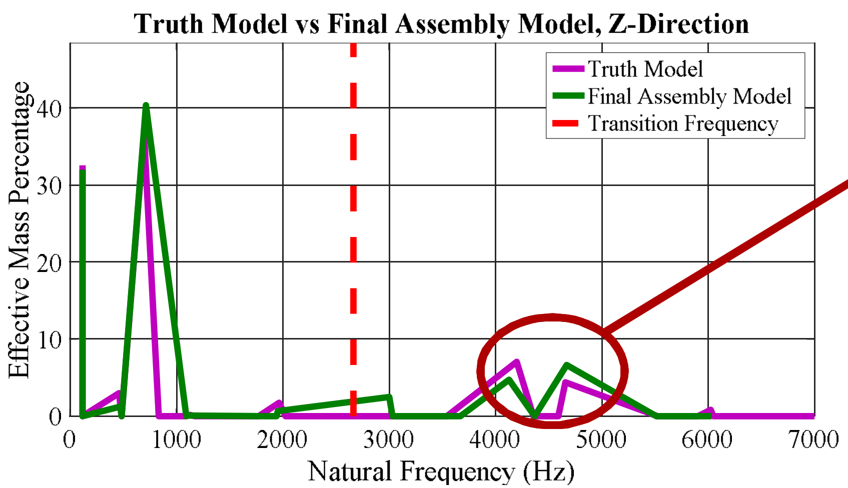




Mode splitting effect, overall energy of these modes captured

Proof of Concept on Physical Hardware

- Previous work by Goodding, et al. shows that cables can be represented by a Timoshenko beam with the rotational inertia term neglected
- We approximated a planar Timoshenko beam by augmenting the Bernoulli-Euler elemental stiffness matrix with

$$\begin{bmatrix} \frac{KAG}{L} & 0 & -\frac{KAG}{L} & 0 \\ 0 & 0 & 0 & 0 \\ -\frac{KAG}{L} & 0 & \frac{KAG}{L} & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

- EI and KAG parameters of the cable Timoshenko beam model were fit via sensitivity analysis to experimental modal data of 2 cable lengths

Length (in)	Mode	% f_n Difference Between Experiment and Model
8	1	9
	2	2
	3	-2
	4	5
6	1	-10
	2	0
	3	-11

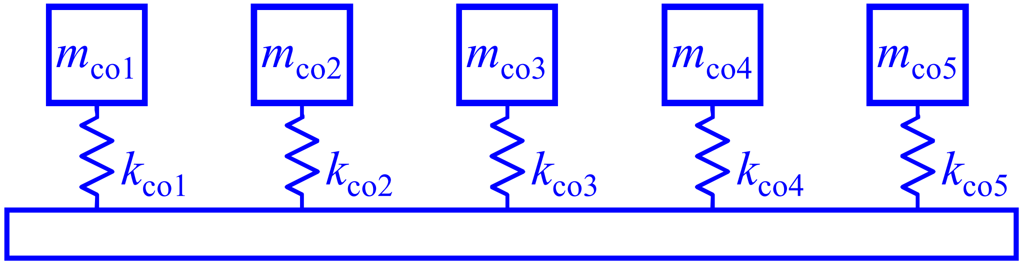
Proof of Concept on Physical Hardware

- The connector effective mass modal model was extracted from modal test data of the connector mounted on a fixture

Mode	Frequency (Hz)	Description	Normalized Effective Mass (%)		
			X	Y	Z
1	768	connector bending in Z	0	2.5	52.3*
2	785	connector bending in X	44.4*	1.4	0
3	1170	cable stub bending in Y	10.1	7	0
4	1264	cable stub bending in Z	0	0.1	0.4
5	1926	connector axial	0	80.2	0.1

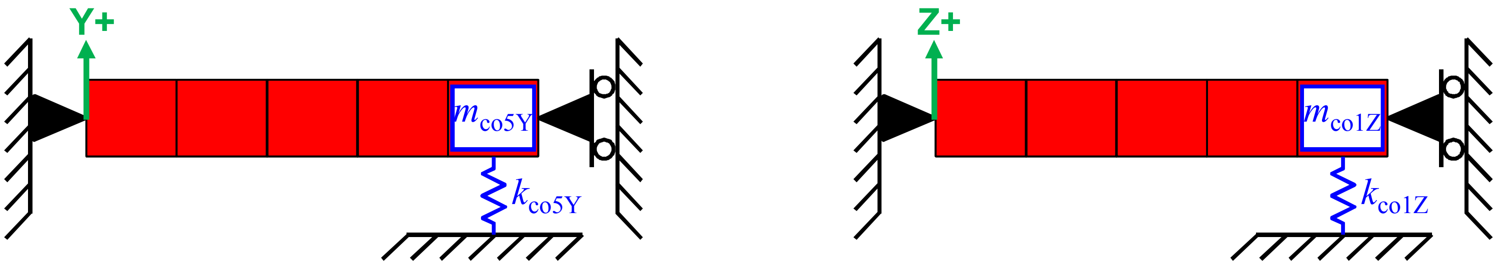
*These values were reconfigured so that effective mass of connector bending is either purely in the X or Z direction

Connector Effective Mass Model



Proof of Concept on Physical Hardware

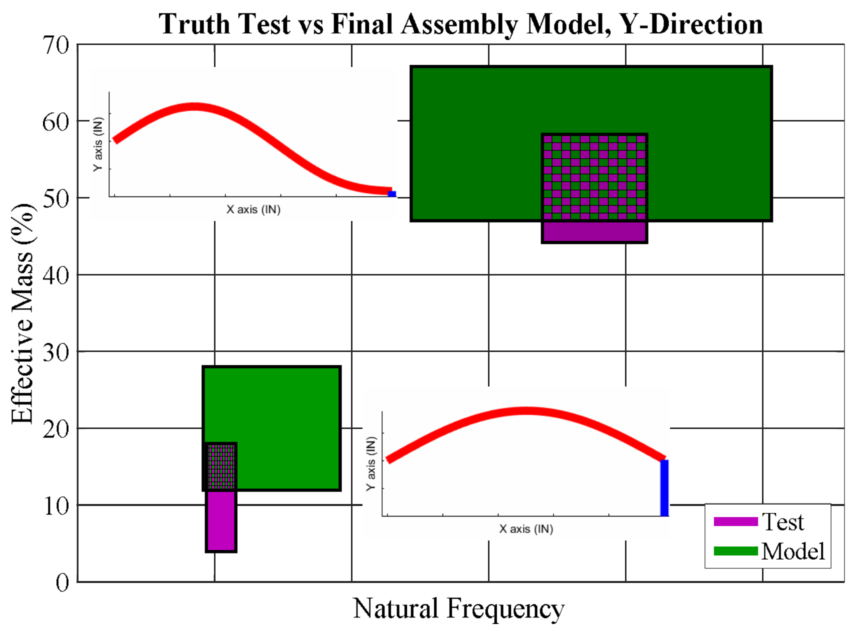
- A numerical model of a cable was created using the fit EI and KAG parameters
- For each direction, this was assembled with the connector mode with the largest effective mass and the final assembly model was calculated

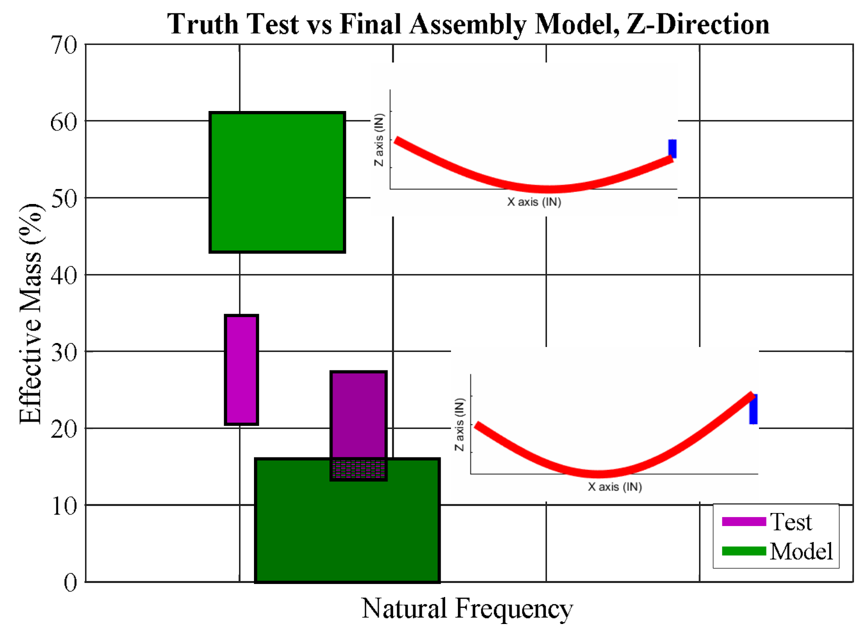


- The results were compared to a truth test
  - Later discovered that the cable length in the truth test was shorter than those used in the EI and KAG fitting process (extrapolation)
- This process included uncertainty bounds based on engineering judgement for the predicted and measured natural frequency and effective mass

Parameter	Source		
	Connecter Experiment	Max Error from Analytical Verification Results	Unit-to-Unit Variability
Frequency	±10% of natural frequency	±6% of natural frequency	±30% of natural frequency
Effective Mass	±7% of total mass	±3% of total mass	±10% of calculated effective mass

Proof of Concept Results





- Cable mode shape in model matches that seen in experiment except for the Connector Axial mode
  - Experiment shows cable in 3rd bending, but the model has 1.5th or 2nd bend
- Mode splitting effect for the Z-direction modes
  - Individual mode-to-mode effective masses are inaccurate, but the overall energy of the two modes is captured

Conclusions

- Ideally the final assembly model results would totally encompass the test results, but the proposed method shows promise
- Generally, the predicted mode shape of the cable matches that seen in the truth test
  - Exception: connector axial mode
- Mode splitting when connector modes are close to cable modes can cause large errors in effective mass for a single mode, but the overall dynamic effect of both modes is captured
- The accuracy of the proposed method is greater for cable-connector assembly modes with large effective mass
- Potential causes for error and areas for further improvements
  - Better quantification of uncertainty
  - More accurate model form?