FT2019

MODAL ANALYSIS OF A BI-DIMENSIONAL TENSEGRITY STRUCTURE SUBJECT TO LARGE DEFORMATIONS

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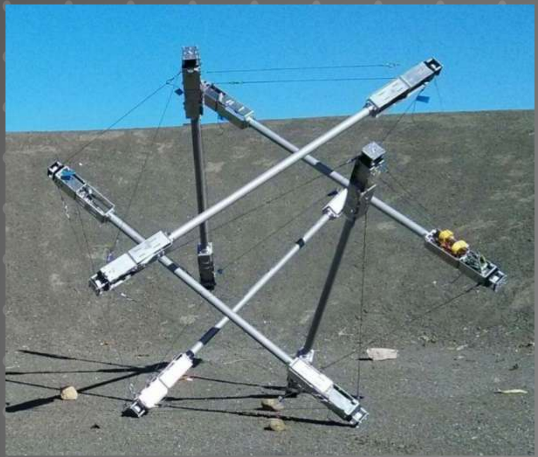
WHAT IS A TENSEGRITY?

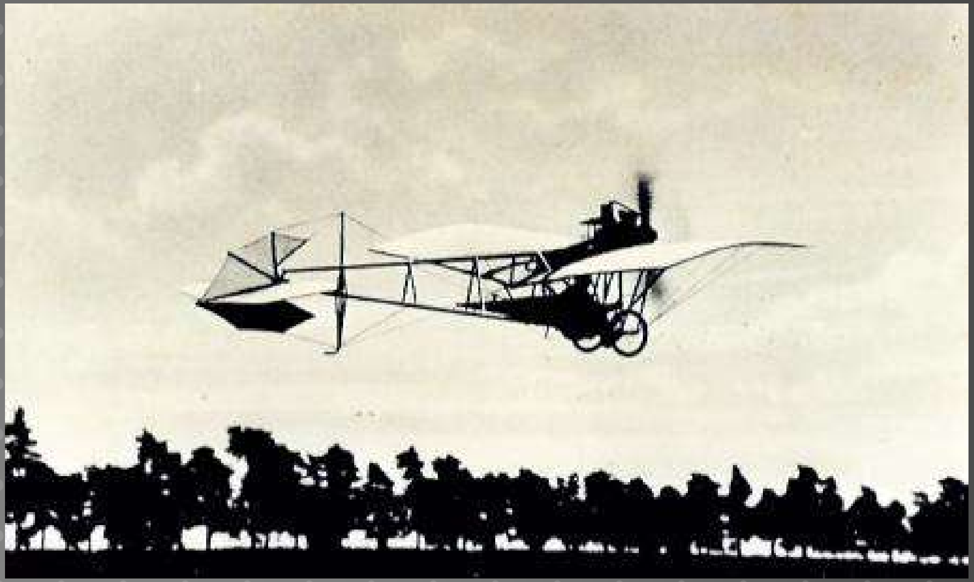
- Set of rigid bodies under compression
- Set of cables under traction
- Set of cables is sufficient and necessary to maintain stability



[NASA 2015]

BENEFITS OF TENSEGRITIES

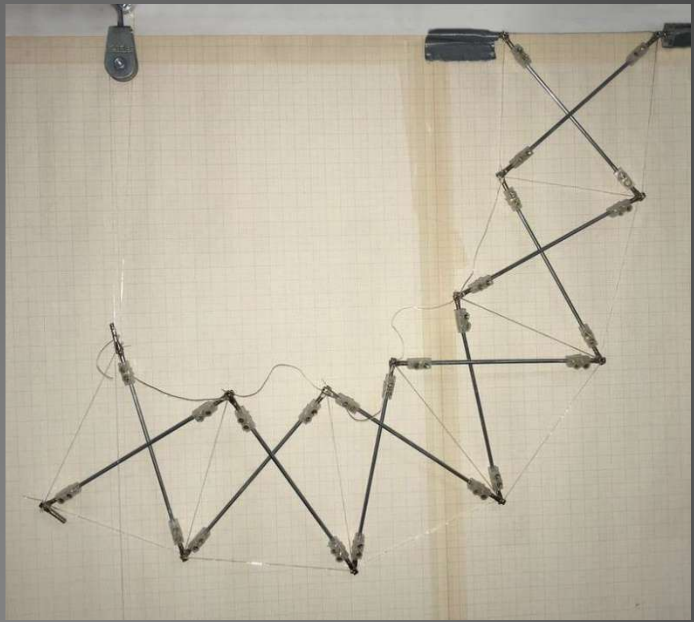
- High structural efficiency
- Uniaxial stress -> easier material selection
- Controllable shape
- Controllable stiffness
- Efficient control strategies
- Deployable



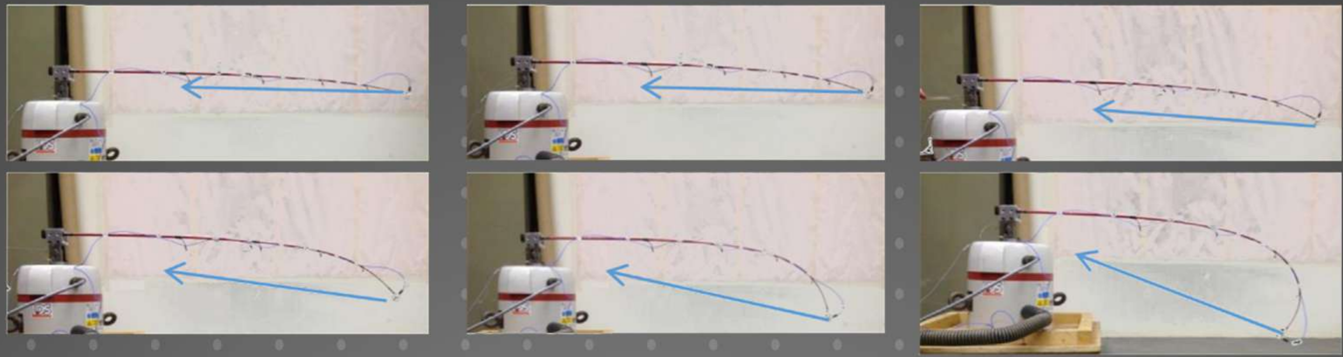
LONG ARMS/MANIPULATORS

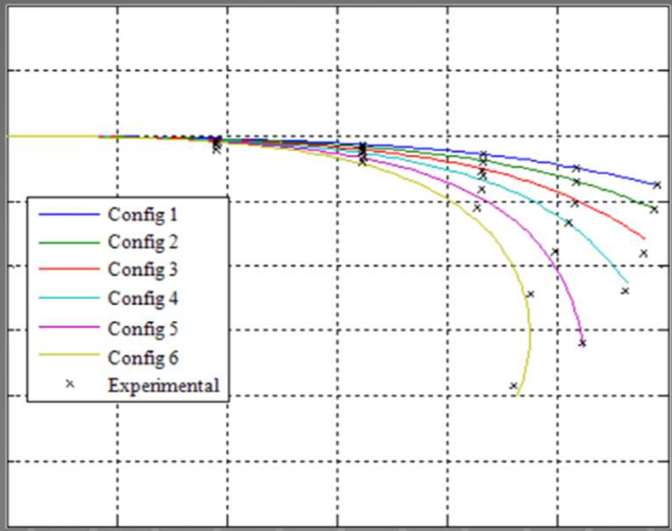
- Agile movements
- High precision
- Lightness
- **Low stiffness**
- **Vibration issues**

How to solve these problems?



PREVIOUS WORK





[Kurka, 2016]

LINEAR STATIC ANALYSIS

- Find the stiffness (Skelton) matrix, then $\{\mathrm{F}\} = [K_G]\{u\}$

Total number of nodes: n

Nodes position matrix: $[N]_{3\times n} = \begin{bmatrix} x_1 & x_2 & & x_n \\ y_1 & y_2 & \ldots & y_n \\ z_1 & z_2 & & z_n \end{bmatrix}$

Connectivity: $\{c_k\}_{n\times 1} = \{e_i\} - \{e_j\}$

Where $\{e_i\}_{n\times 1} = \begin{Bmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{Bmatrix} \leftarrow i$

LINEAR STATIC ANALYSIS

Total number of members: m

Connectivity matrix: $[C^T]_{n\times m} = [\{c_1\} \quad \{c_2\} \quad \ldots\{c_m\}]$

Members matrix: $[M]_{3\times m} = [N]_{3\times n}[C^T]_{n\times m} = [\{m_1\} \quad \{m_2\} \quad \ldots\{m_m\}]$

k^{th} member stifness: $[K_k]_{3n\times 3n} = \{c_k\}_{n\times 1}\,\{c_k^T\}_{1\times n} \otimes [L_k]_{3\times 3}$

Where $[L_k]_{3\times 3} = s_k\left([I_3]_{3\times 3} - \frac{\{m_k\}_{3\times 1}\,\{m_k^T\}_{1\times 3}}{\|m_k\|^2}\right) + K_B \cdot \frac{\{m_k\}_{3\times 1}\,\{m_k^T\}_{1\times 3}}{\|m_k\|^2}$

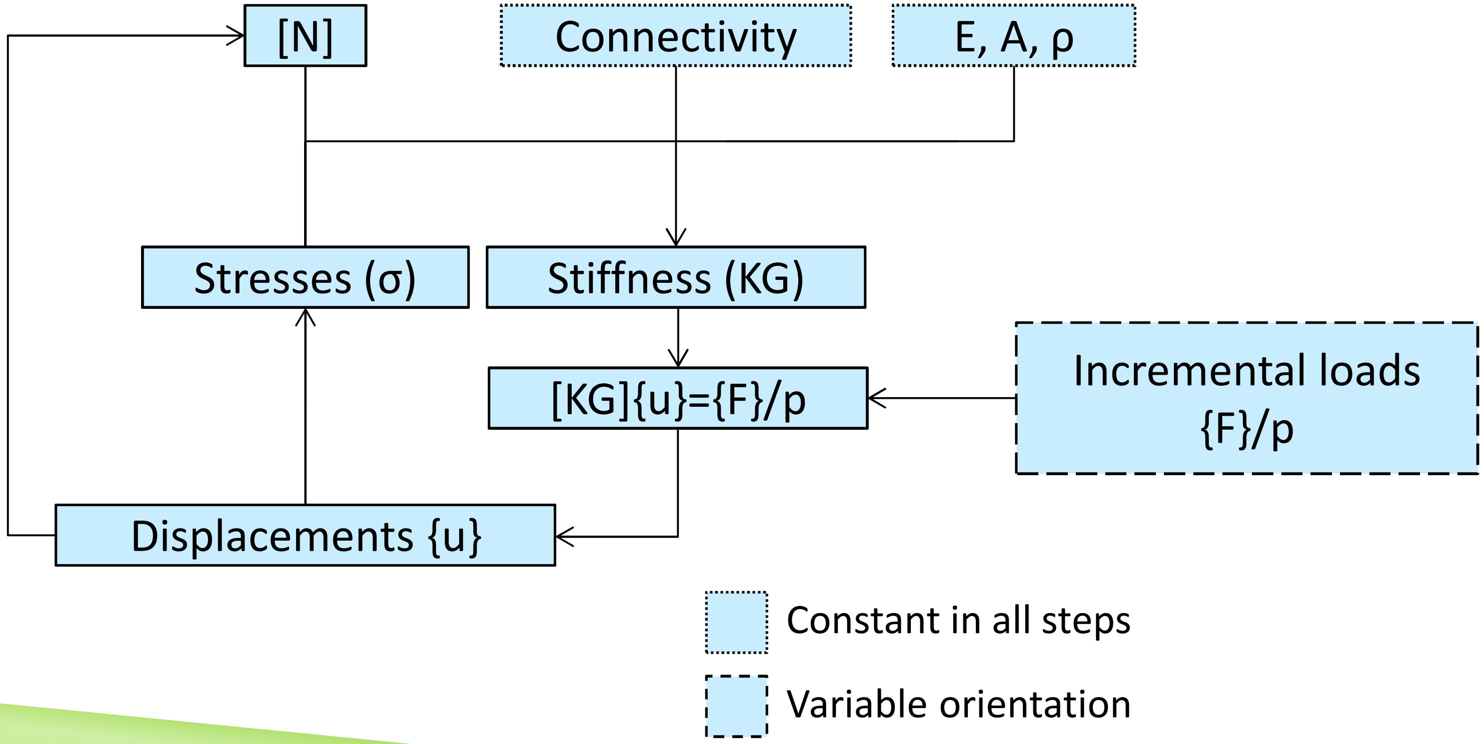
$$s_k = \frac{F}{l}$$

$$[K_G] = \sum_{k=1}^{m}[K_k]$$

$$[H]_{i\times j} \otimes [G] = \begin{bmatrix} H_{11}[G] & H_{12}[G] & \cdots & H_{1j}[G] \\ H_{21}[G] & H_{22}[G] & \cdots & H_{2j}[G] \\ \vdots & \vdots & \ddots & \vdots \\ H_{i1}[G] & H_{i2}[G] & \cdots & H_{ij}[G] \end{bmatrix}$$

NONLINEAR STATIC ANALYSIS

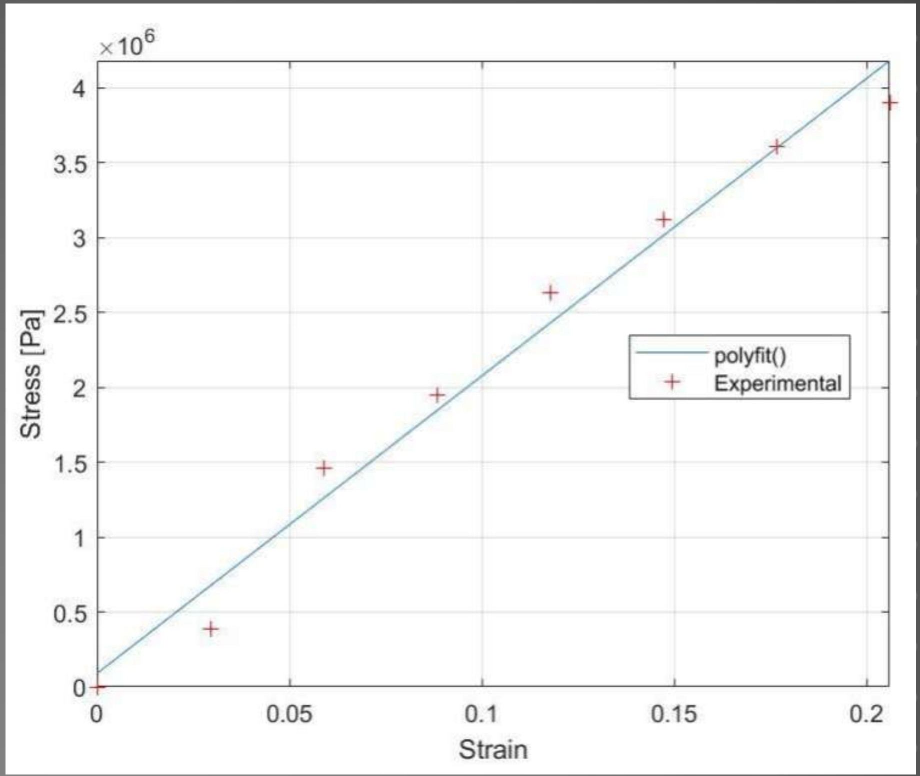
- Combination of Skelton and Euler (incremental loads) methods
- Variable pre-stresses
- Large displacements



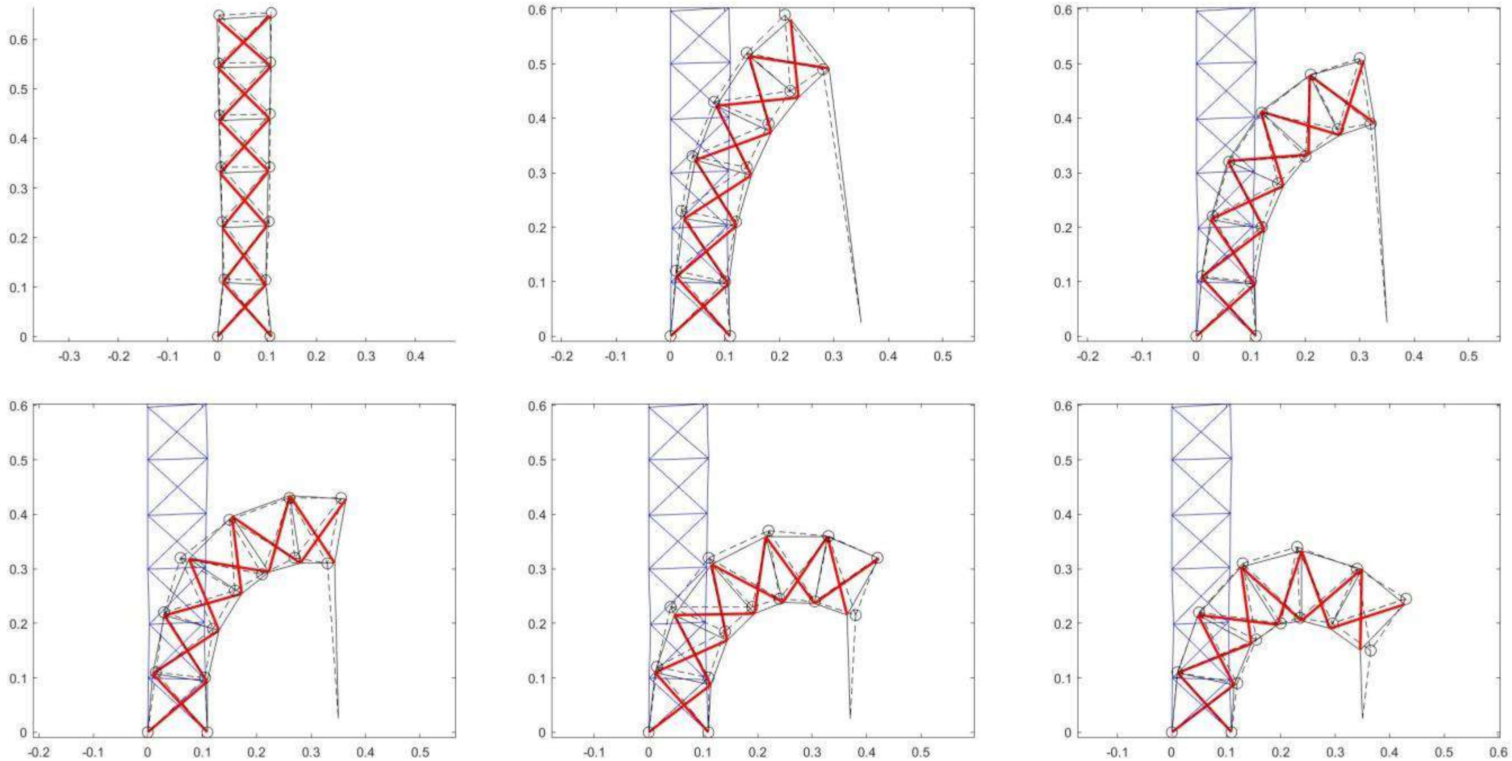
NONLINEAR STATIC ANALYSIS

- Estimate of the Young modulus of the cables:

$$E \cong 19.9MPa$$

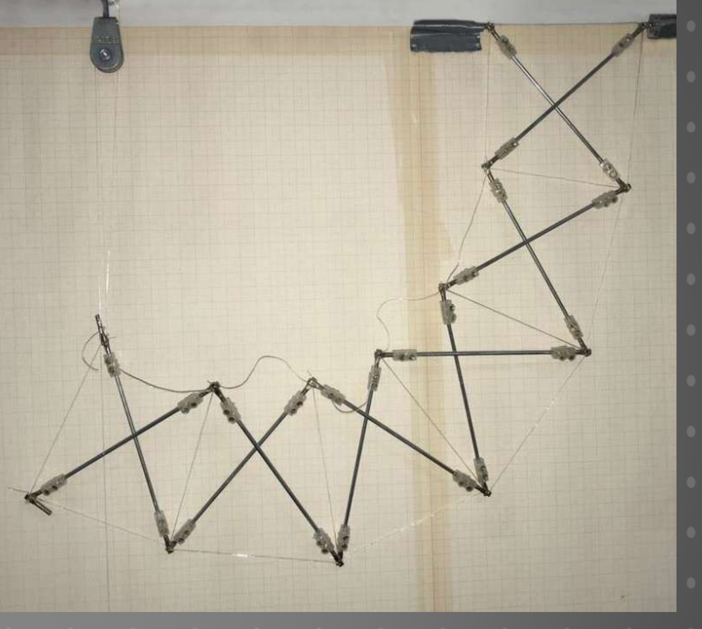


RESULTS

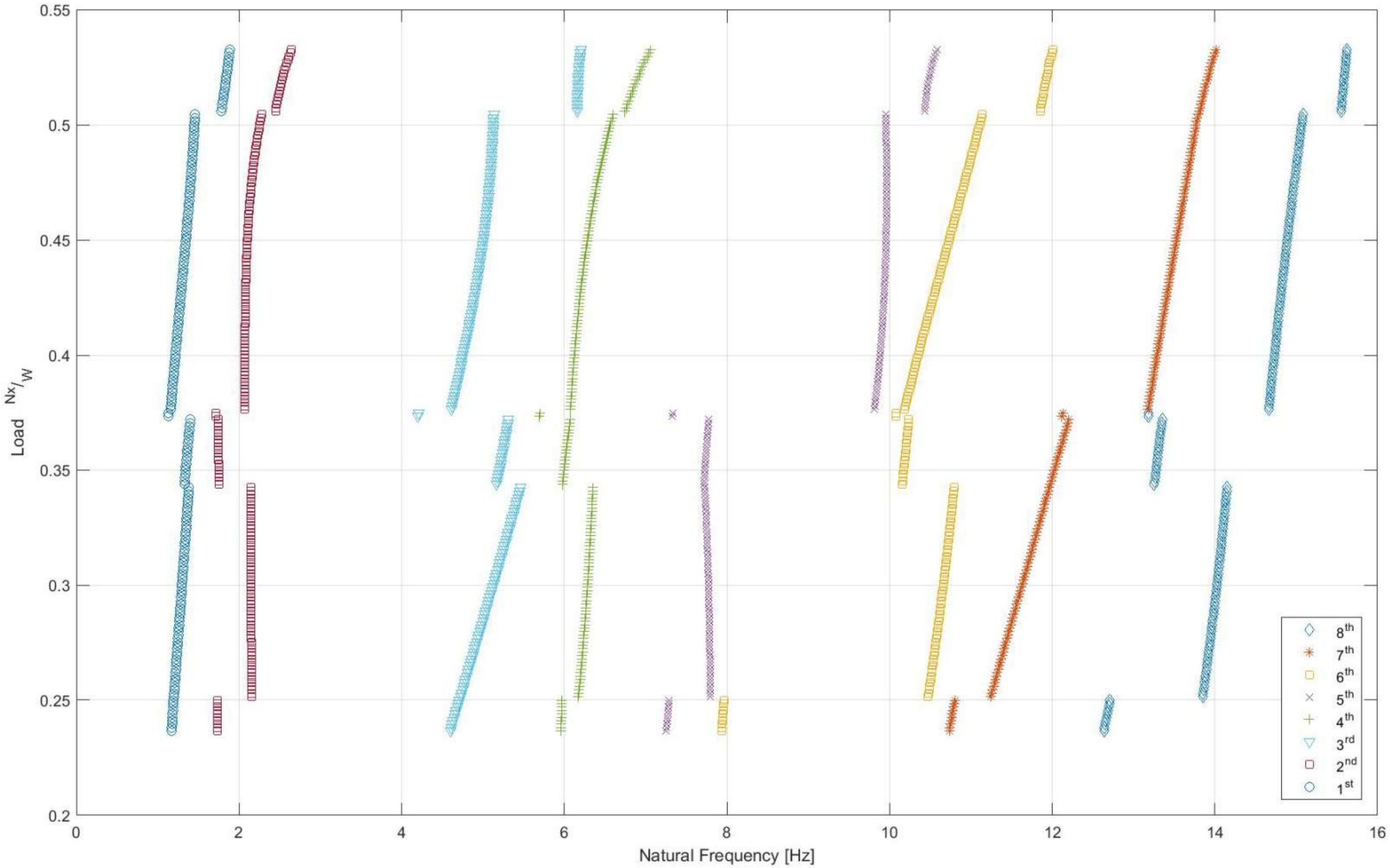


EXPERIMENTAL PROCEDURE

- Class 2 tensegrity 2D tower pulled by nylon cable under known loads
- Loads : 0, 0.03, 0.044, 0.052,0.061 and 0.066 kgf
- Deformed configurations were instantly acquired from the grid behind.
- Silicone cables



MODAL ANALYSIS



CONCLUSIONS

- Tensegrity systems offer many advantages over traditional structures, such as controllable stiffness, controllable shape and deployable geometry.
- The natural frequency increases with a higher load
- The slack cables produces shifts in natural frequencies
- The methodology used to calculate the stiffness matrix and the deformation for nonlinear static analysis presented results with good agreement with the experimental ones.

THANK YOU