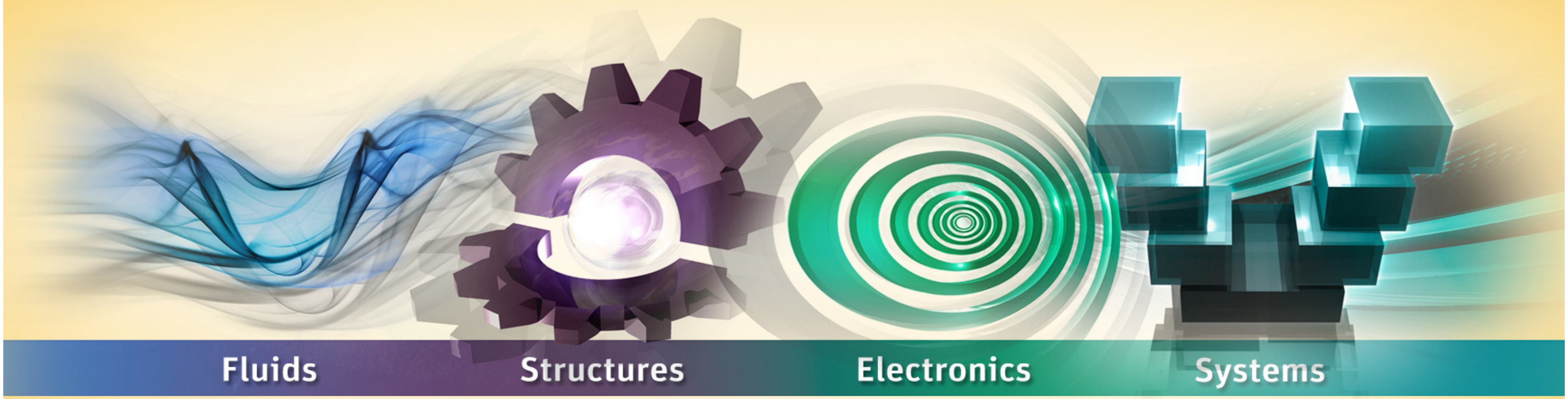
Push-over Analysis of the Main Tower of the New Self-Anchored Suspension Bay Bridge



A. Astaneh-Asl and X. Qian
University of California, Berkeley

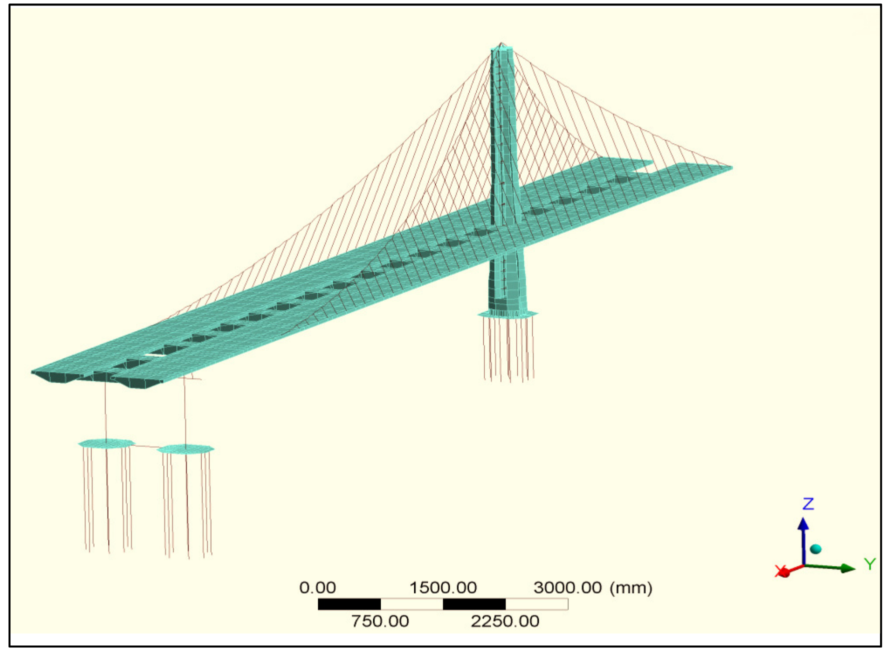
M. Ozen
Ozen Engineering Inc.

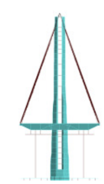
Brief Introduction to “Bay Bridge R&D Project” at the University of California, Berkeley

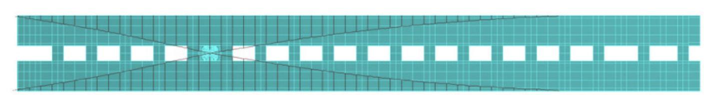
- ❑ Principal Investigator: Abolhassan Astaneh-Asl, Ph.D., P.E.
- ❑ Co-Investigators: X. Qian, D. Miller, J. Chen, S. Chen, Dr. J. Son, Dr. M. Ozen, Dr. M. Tabbakhha
- ❑ Duration: 1989-Present (Studies of the New Bay Bridge since 1997)
- ❑ More than 9,000 of research hours spent on the project.

Projects on the New Self-Anchored Suspension Bay Bridge

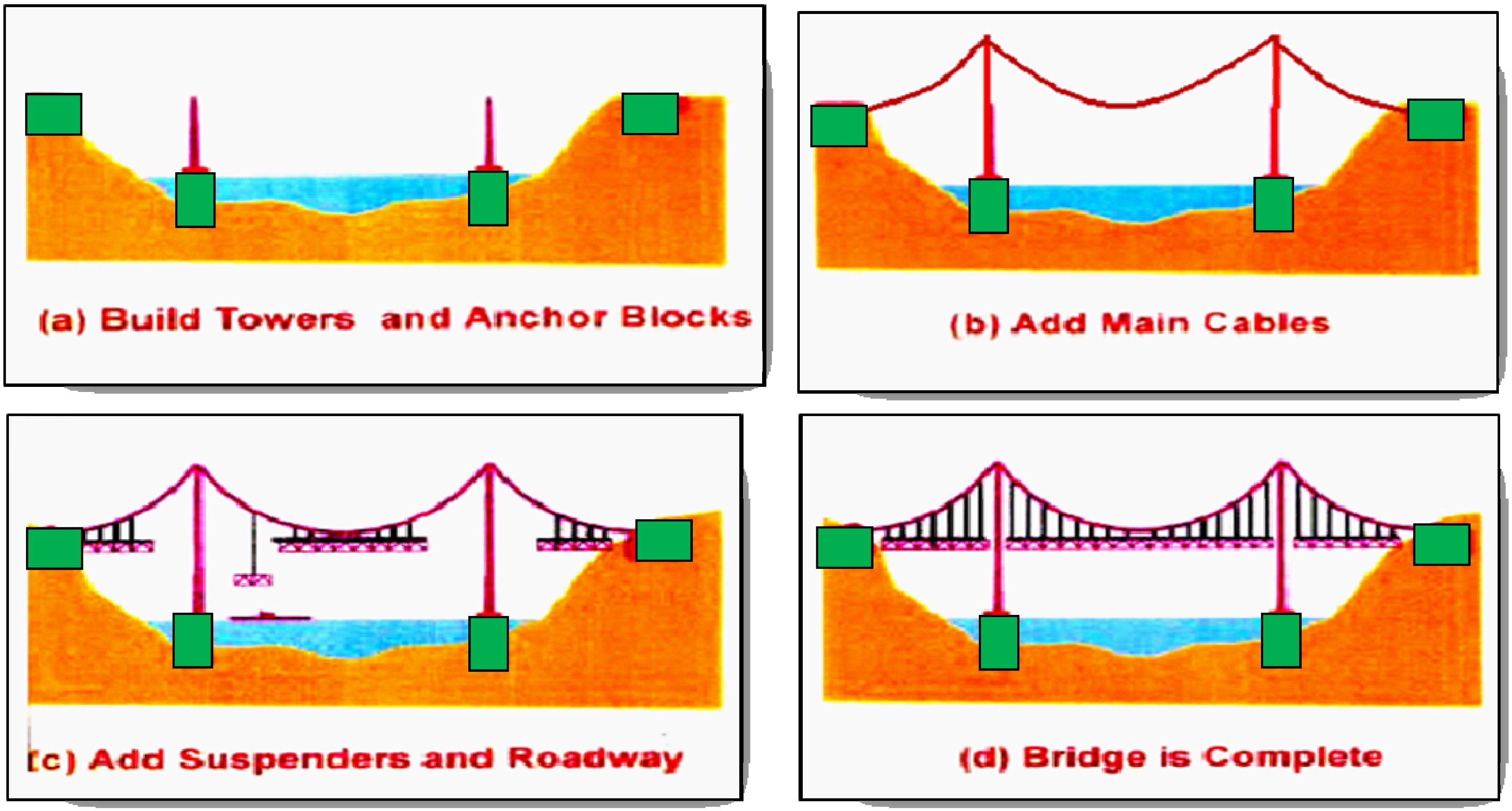
1. **Tower Push-Over**
2. **Anchors at the Tower Base**
3. **Tower Out-of-Plumbness**
4. **Welds at the Base of the Tower**
5. **Welded Deck**
6. **Welded Steel/Concrete Piles**
7. **Anchorage of Main Cables to the Deck**
8. **East Pier Galvanized Bolts**
9. **Hot-dip Galvanized Bolts**
10. **East and West End Expansion Joints**
11. **Blast effects on SAS Bay bridge**





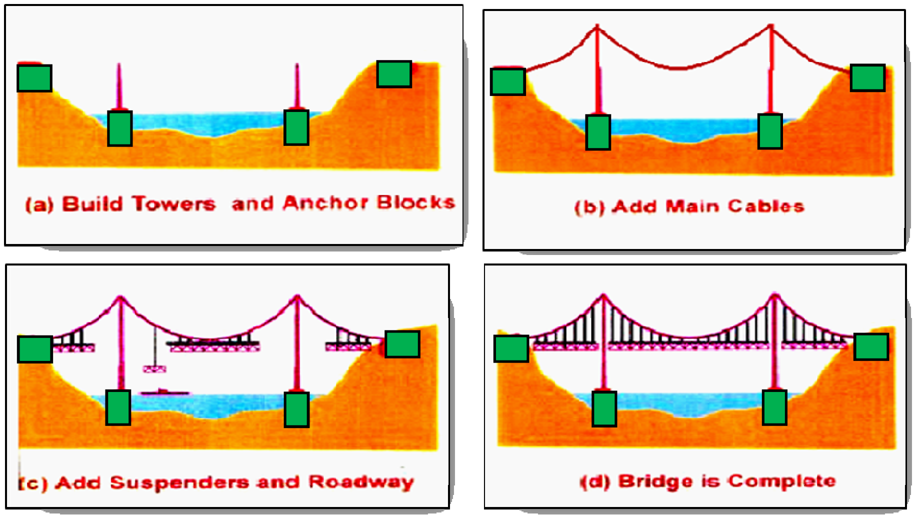


Construction of a Typical "Ground-Anchored" Suspension Bridge



ANSYS

Examples of Construction of Typical "Ground-Anchored" Suspension Bridges Around the World



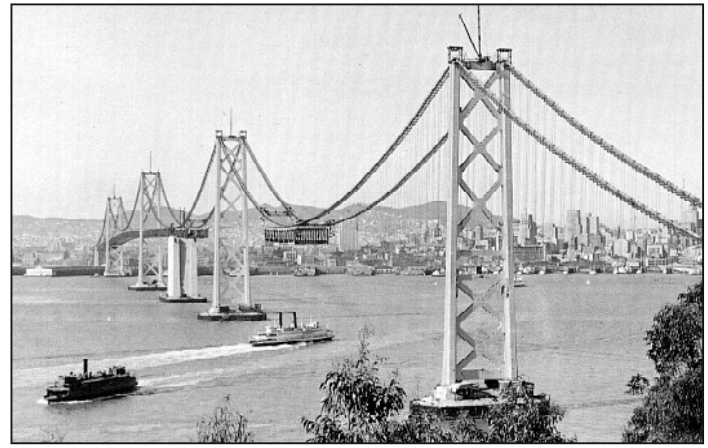


Photo: California Public Works Department

West spans of the Bay Bridge

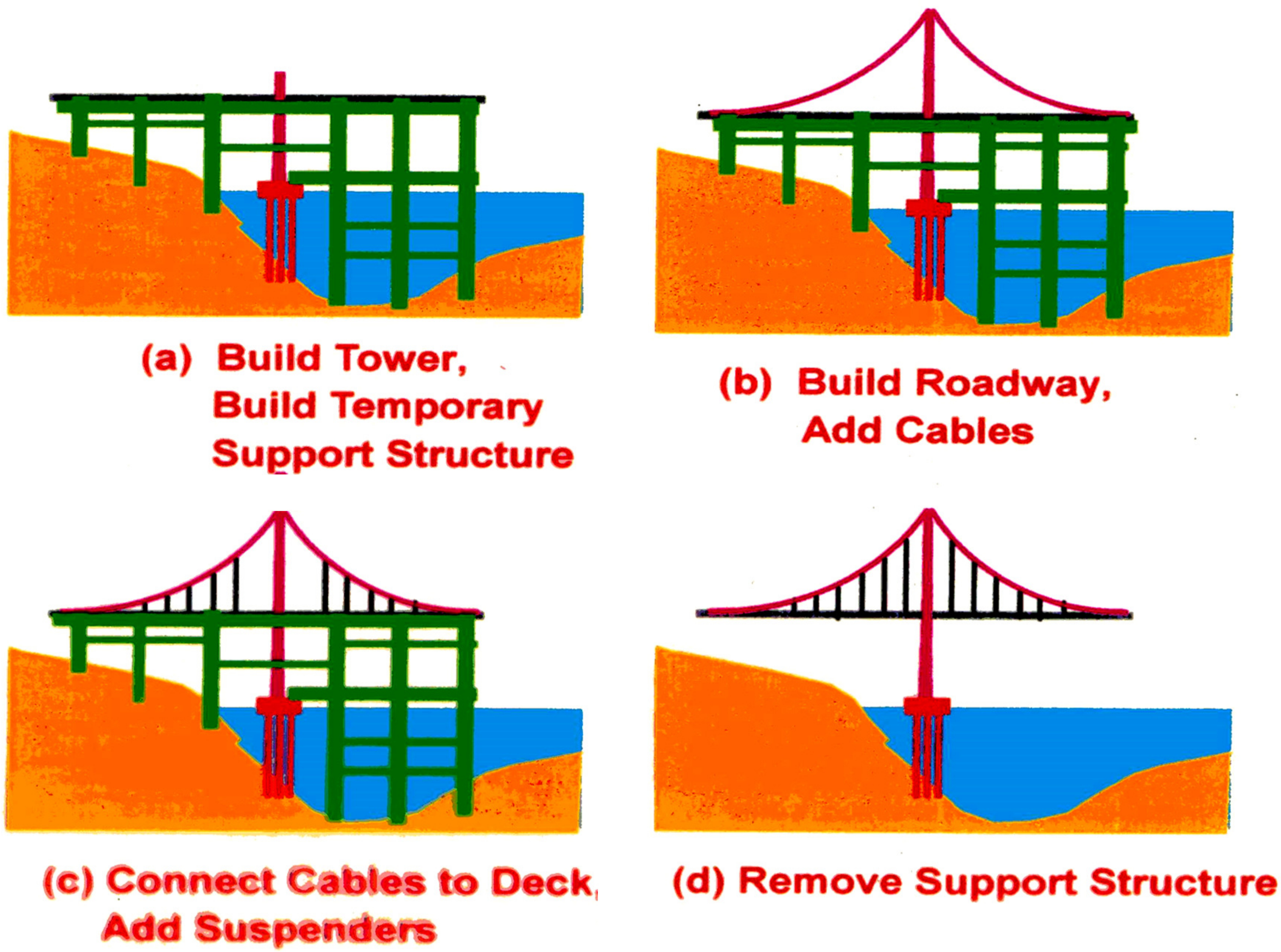
Great Belt, Denmark

Akashi-Kaikyo, Japan

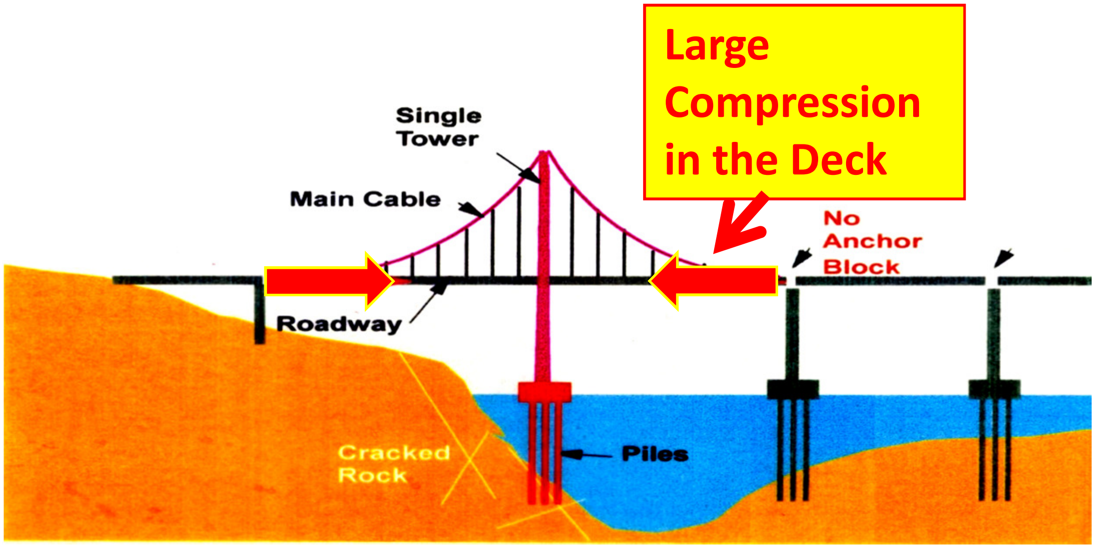
Photo: Golden Gate Bridge, highway and Transportation District

Golden Gate

Construction of a "Self-Anchored" Suspension Bridge



Example of "Self-Anchored " Suspension Bridge

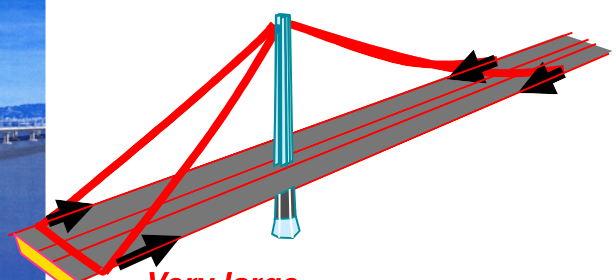


www.mageba.cn

Yeongjong Grand Bridge, S. Korea

Metropolitan Transportation Commission

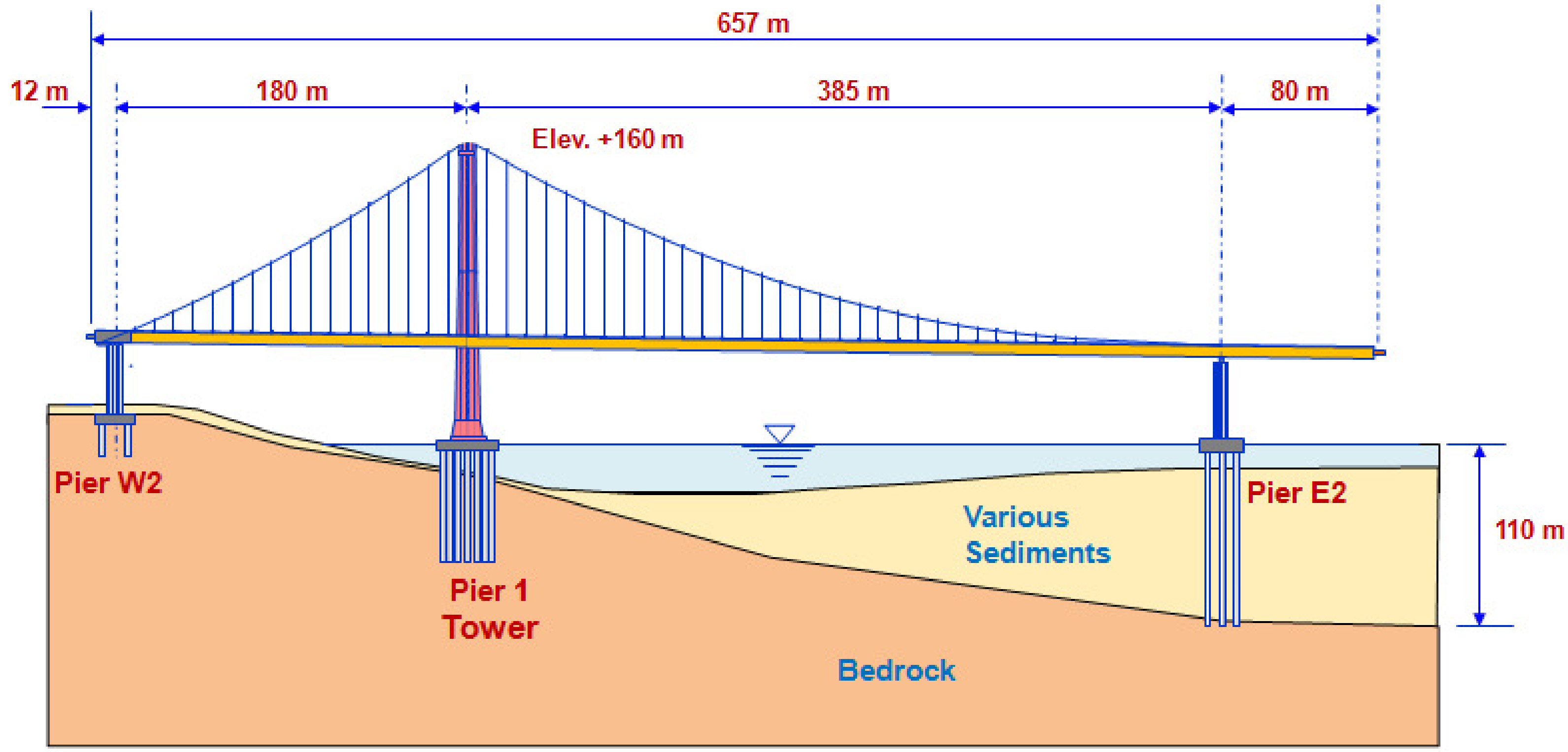
The New SAS Bay Bridge (Subject of these studies)

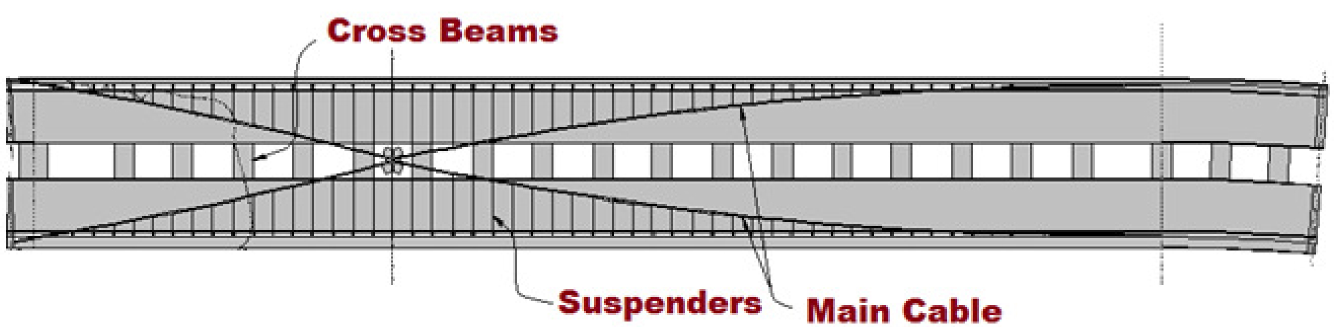


ilmuanggaputra.blogspot.com

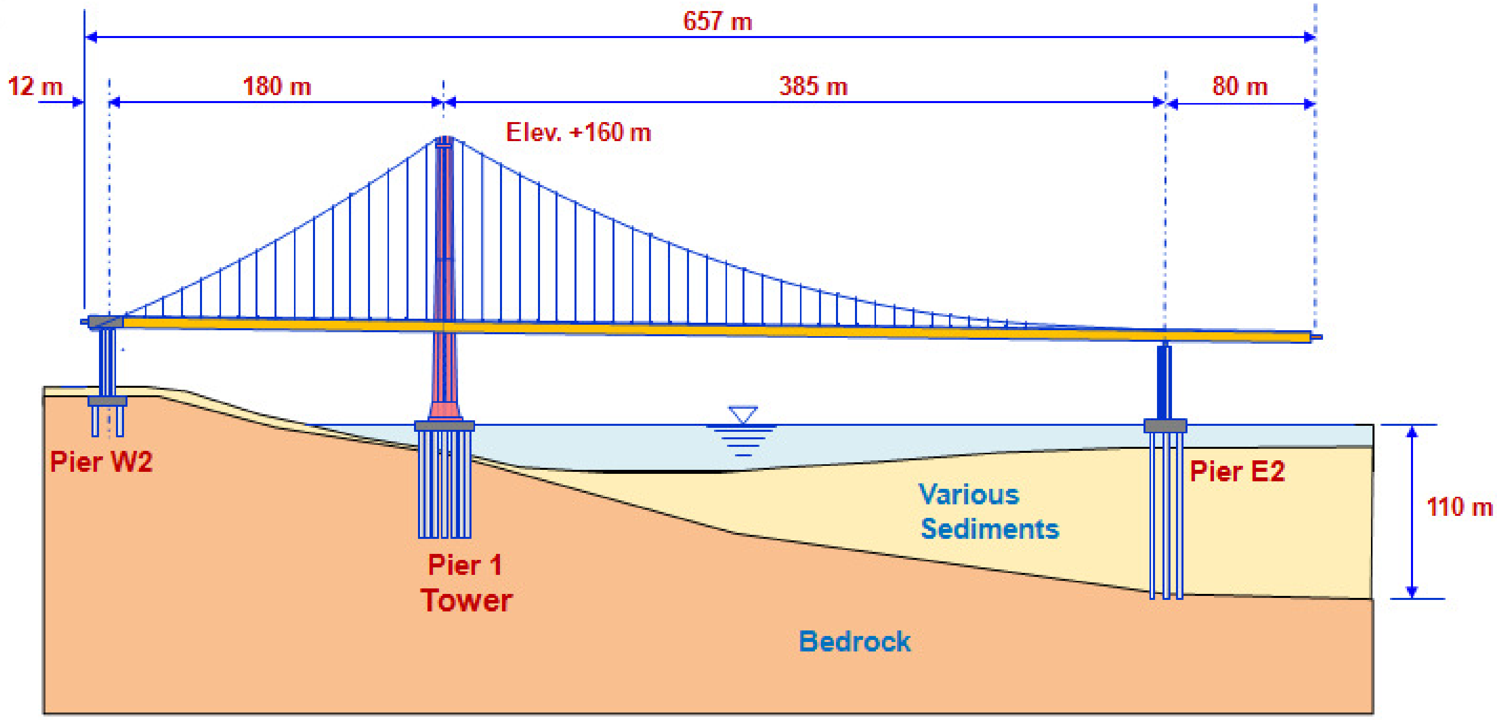
Konohana Bridge, Japan

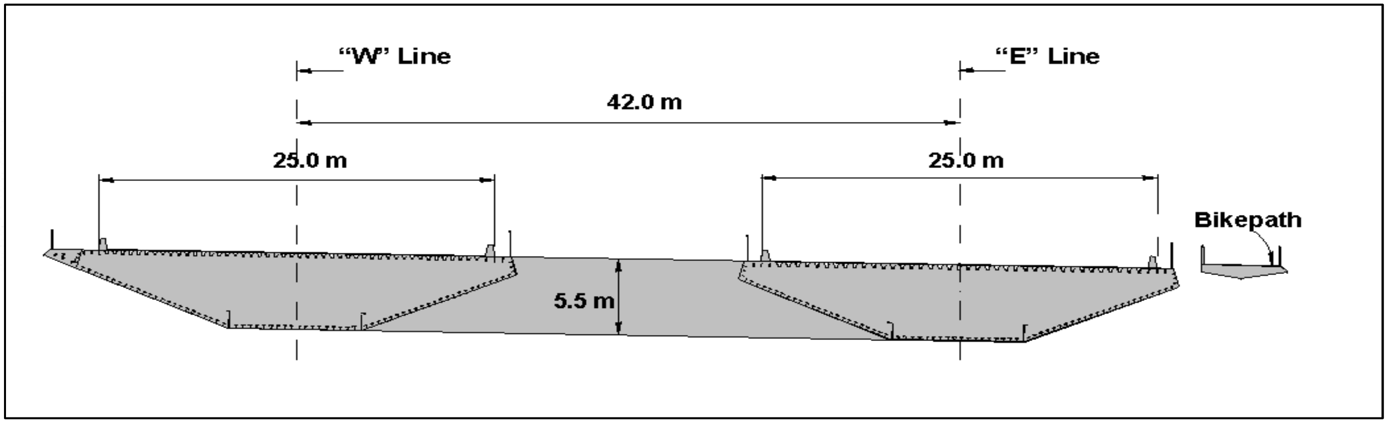
The Self-Anchored Suspension Bay Bridge



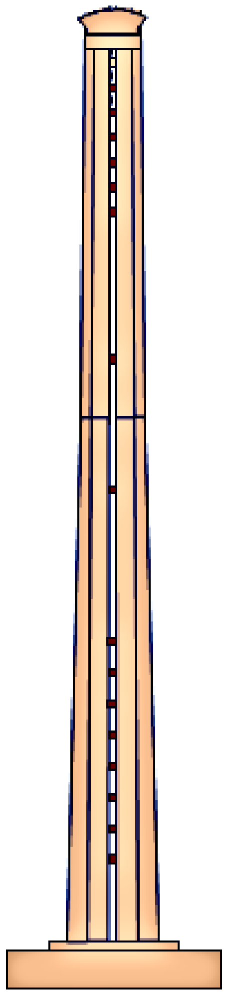


The Self-Anchored Suspension Bay Bridge

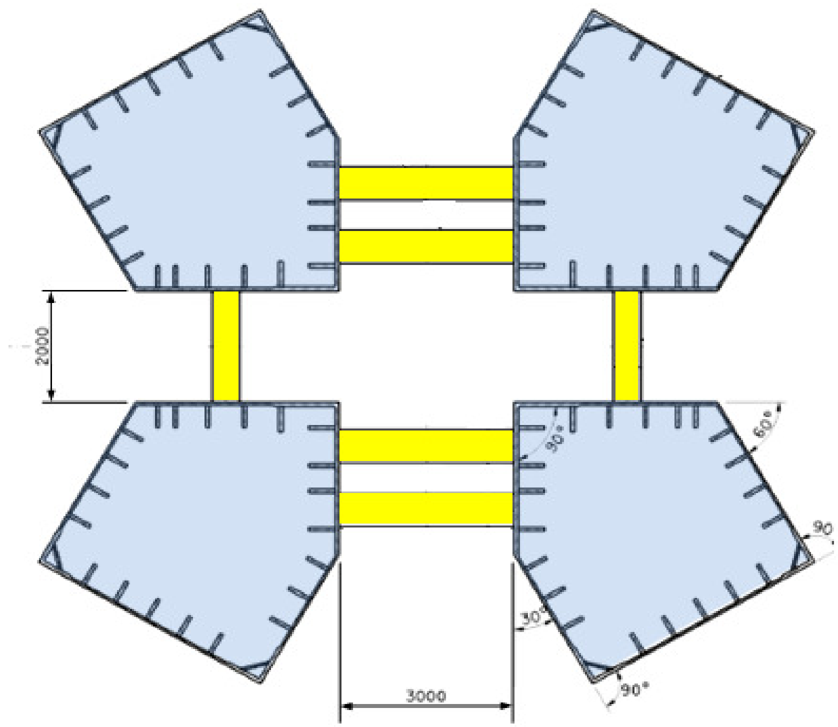




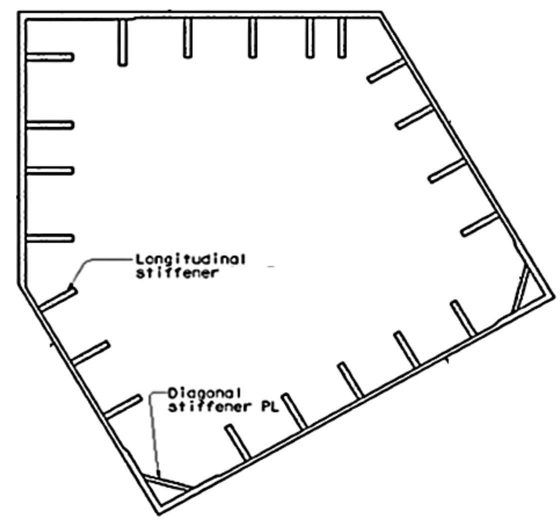
Tower and Typical Tower Cross Section



Tower



Cross Section of Tower

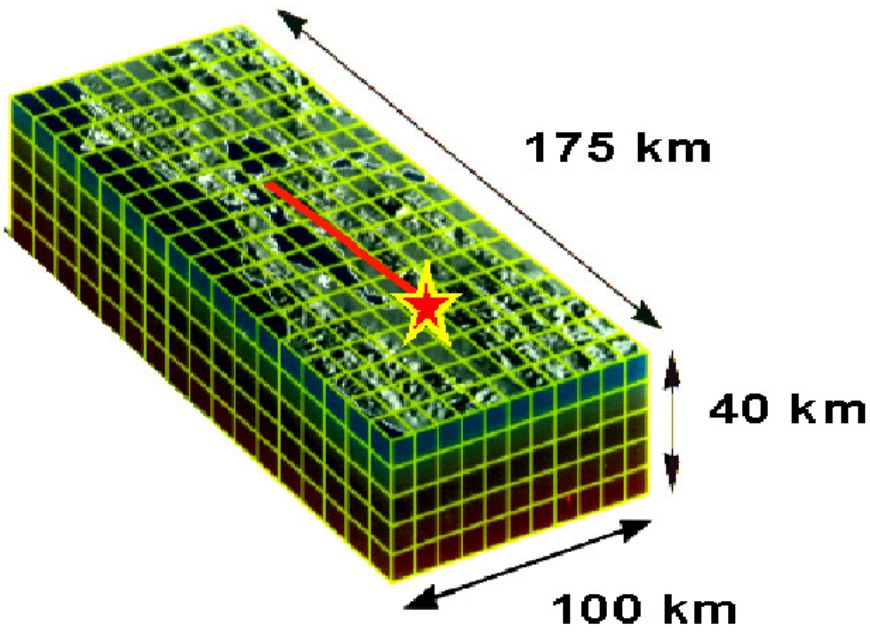


Cross Section of One Leg of Tower

Seismic Performance of Long Span Suspension Bridges

A Joint Project of UC Berkeley and LLNL

A. Astaneh-Asl, D. McCallen, S. Larson

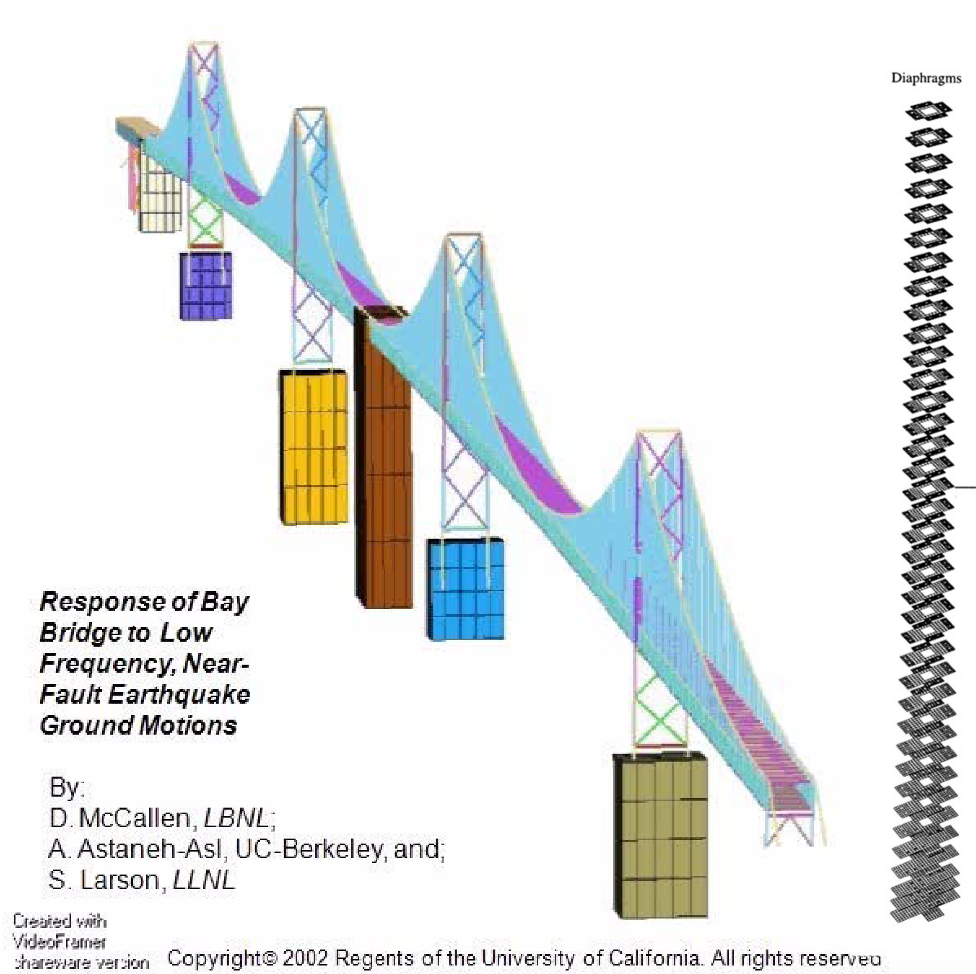


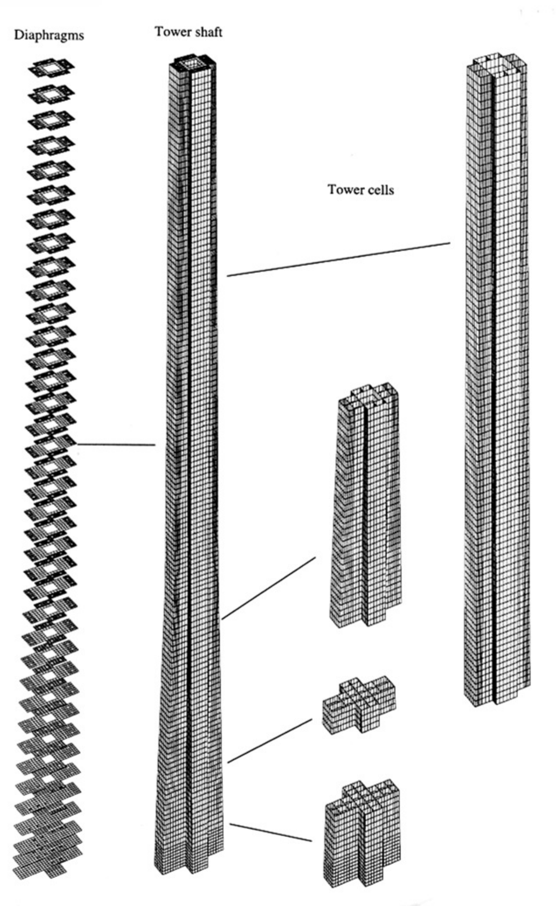
Establishing Ground Motions

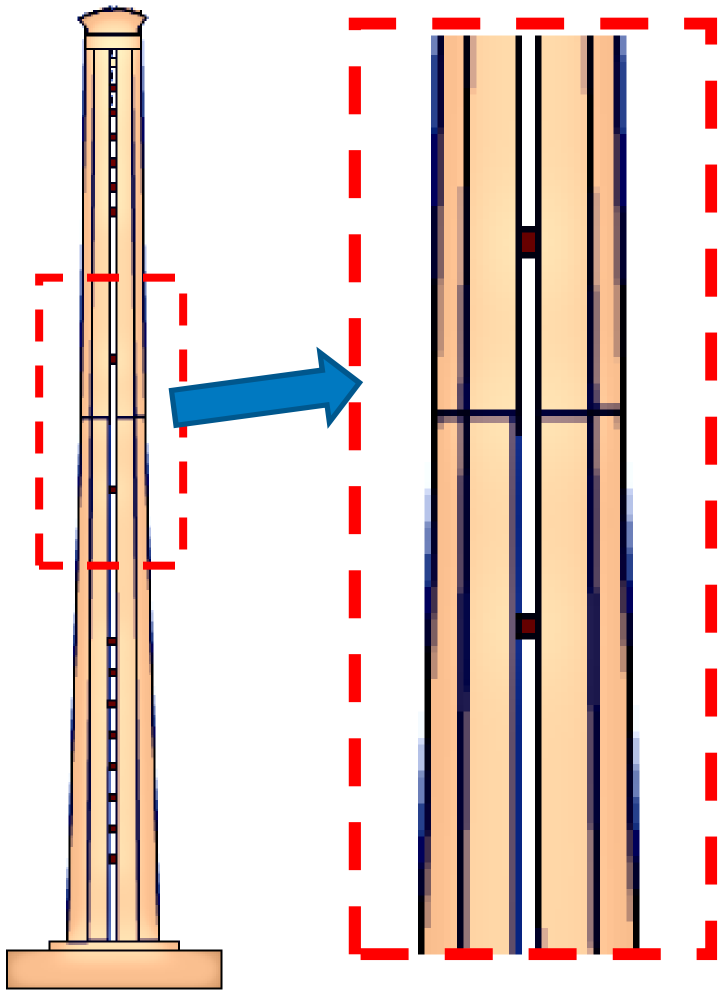
Seismic Performance of Long Span Suspension Bridges

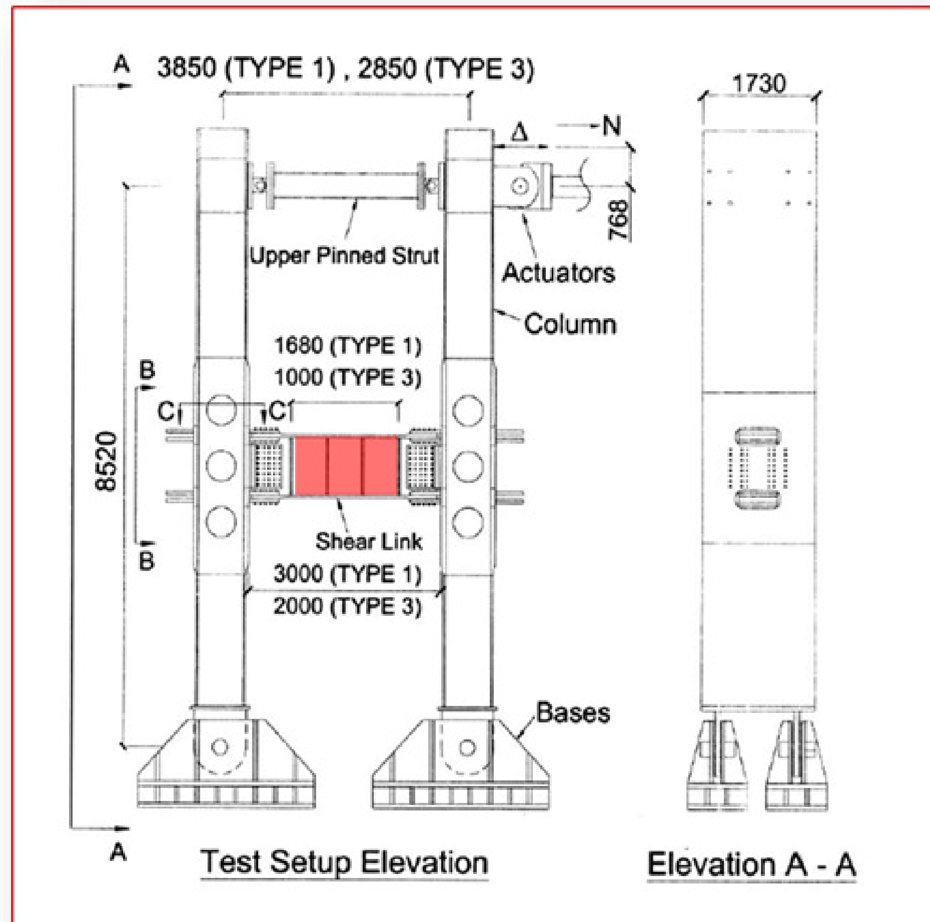
A Joint Project of UC Berkeley and LLNL

A. Astaneh-Asl, D. McCallen, S. Larson

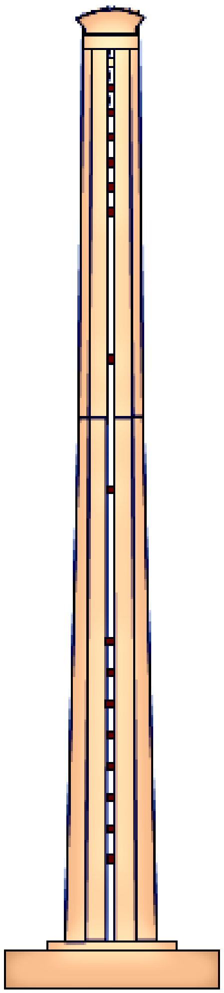


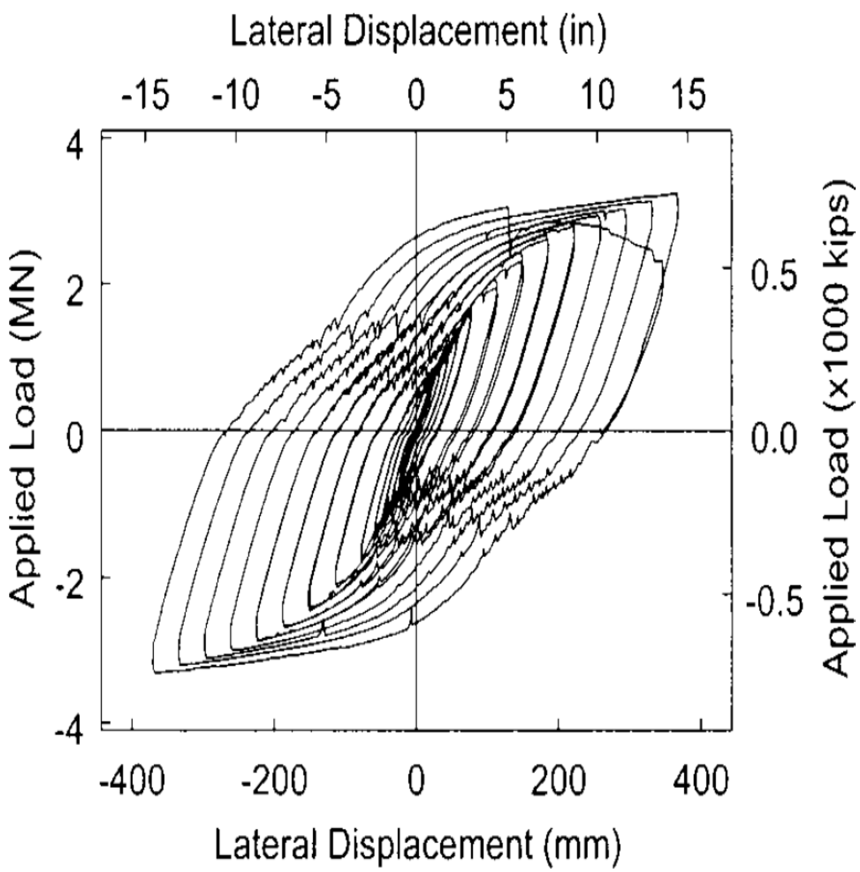


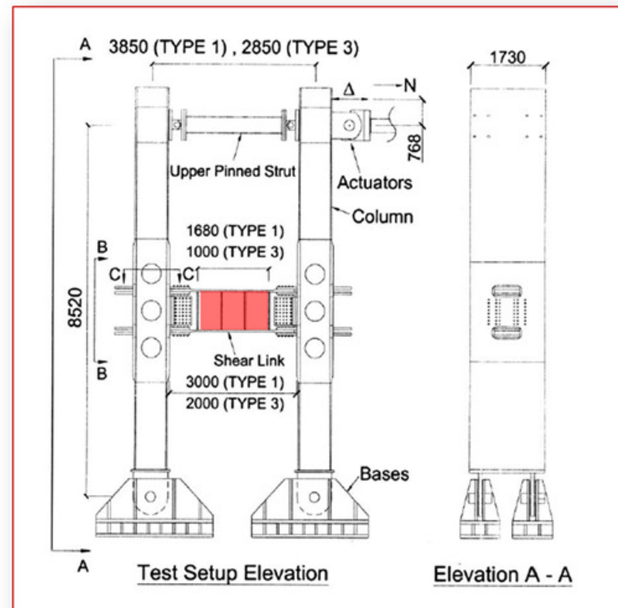




STRUT TYPE 3 DETAILS

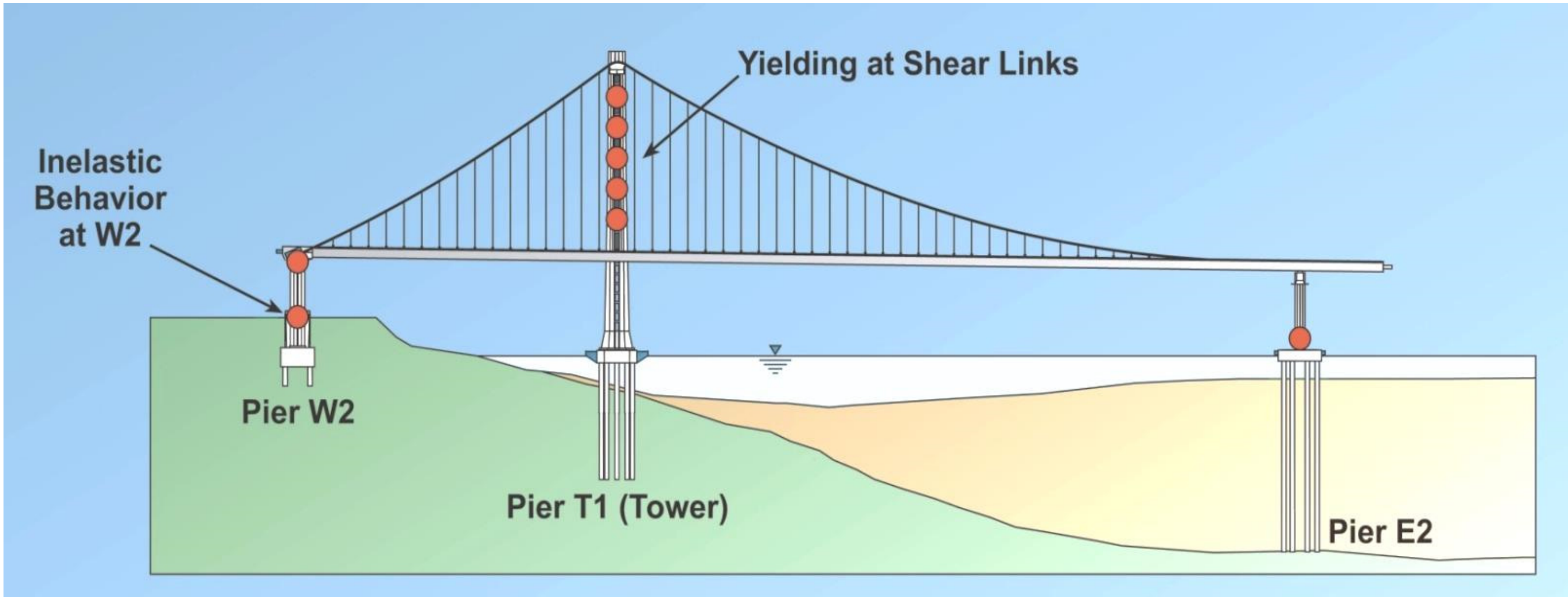






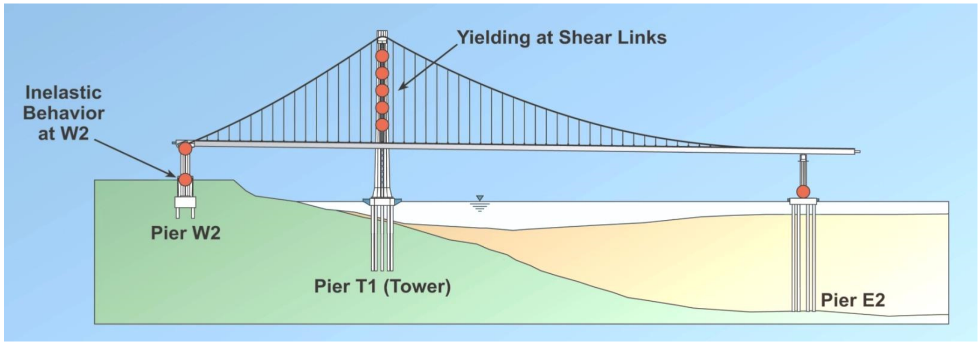
STRUT TYPE 3 DETAILS

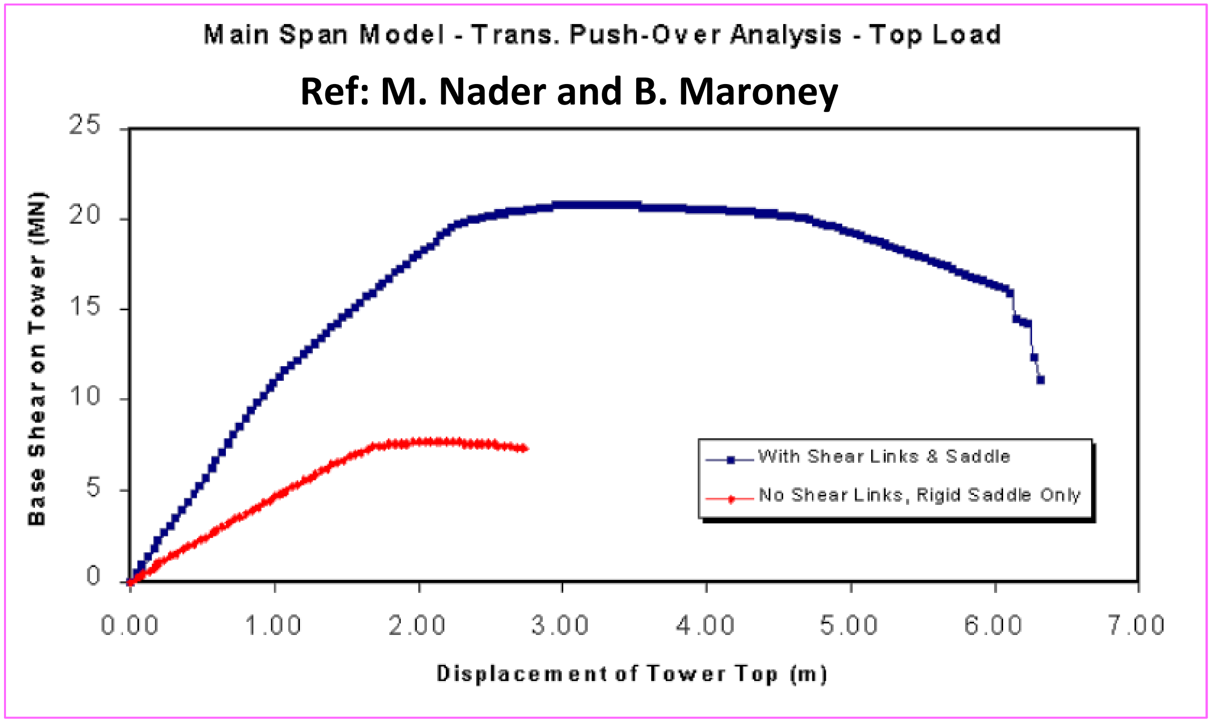
Designers Concept of Seismic Resistance and Ductile Energy Dissipation Mechanism for SAS Bay Bridge



Ref: M. Nader and B. Maroney

Designers' Concept of Seismic Resistance and Ductile Energy Dissipation Mechanism





ANSYS

UC Berkeley/Ozen Engineering Inc. Push-Over Analysis

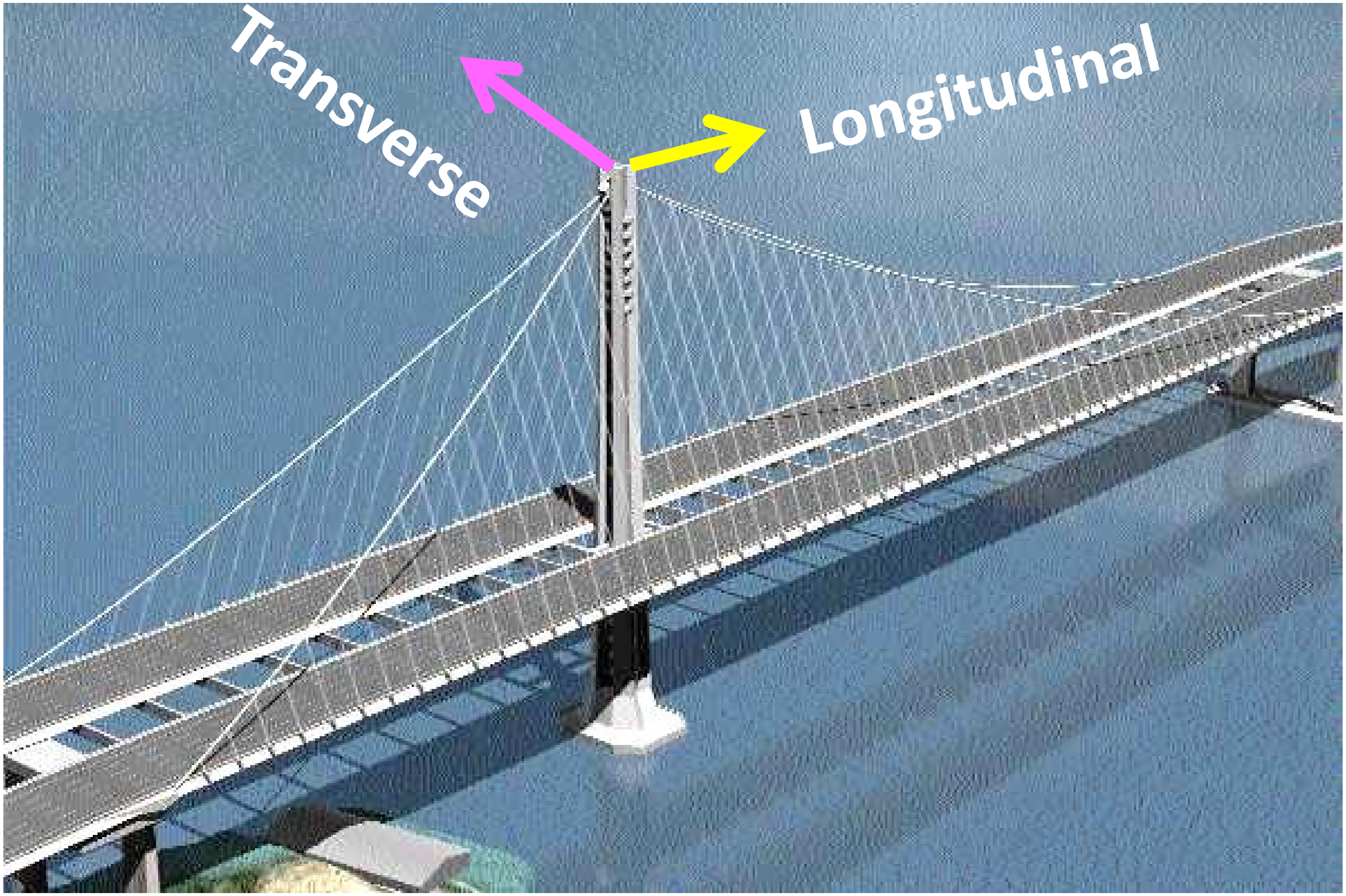
Main Objective:

To perform Lateral Push-Over of the Tower and establish its Performance up to collapse

Research Methodology:

We built a FE model of the tower in ANSYS and subjected it to two separate push-overs by pushing the top of the tower horizontally in longitudinal and transverse directions.

The Directions of Push-Over

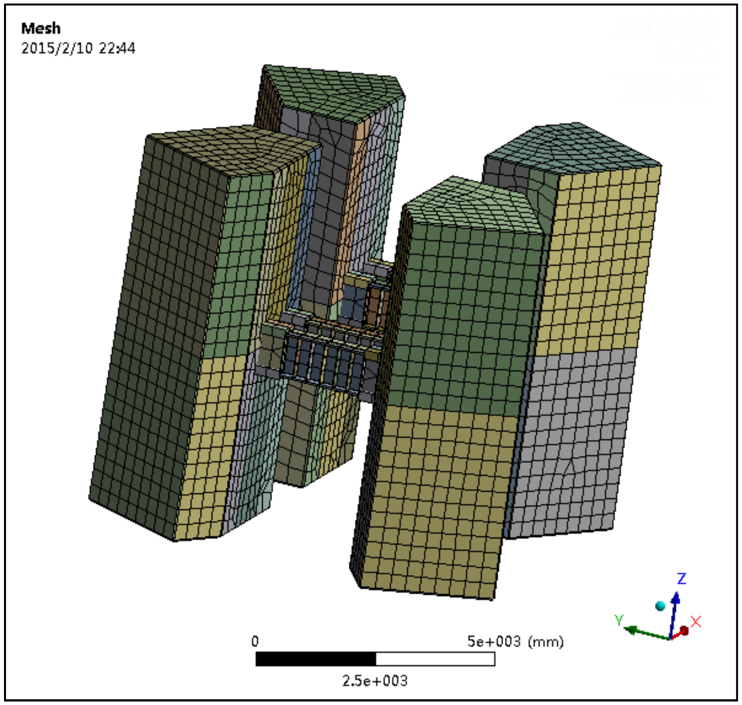


Metropolitan Transportation Commission

Material Model

All material of tower legs and shear link is Grade 50 steel with Fy (yield stress) of 345 MPA (50 ksi).

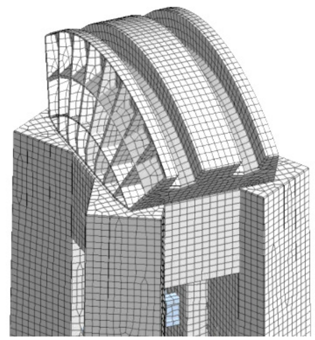
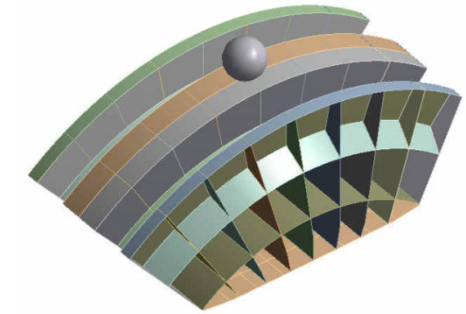
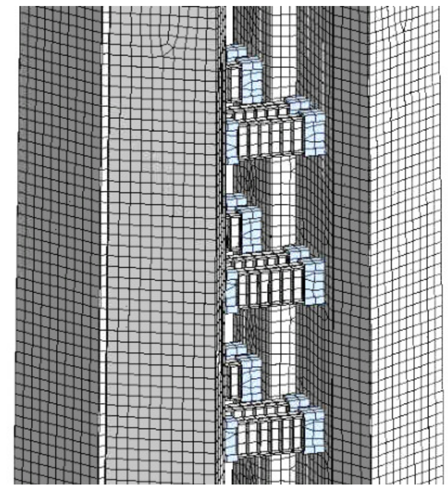
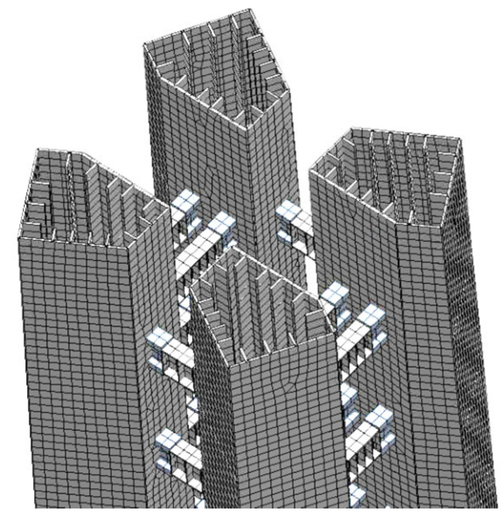
The monotonic stress-strain model is bi-linear kinematic hardening with initial stiffness equal to 200 GPA and hardening branch with modulus of 2 GPA.



Geometry

- Exact geometry based on construction drawings
  - Changed cross-section along the height of tower
  - Included all three types of shear links

- Important structural details were included which are:
  - Tower skin stiffeners
  - Tower leg diaphragms
  - Saddle
  - Tower grillage between tower top and the saddle

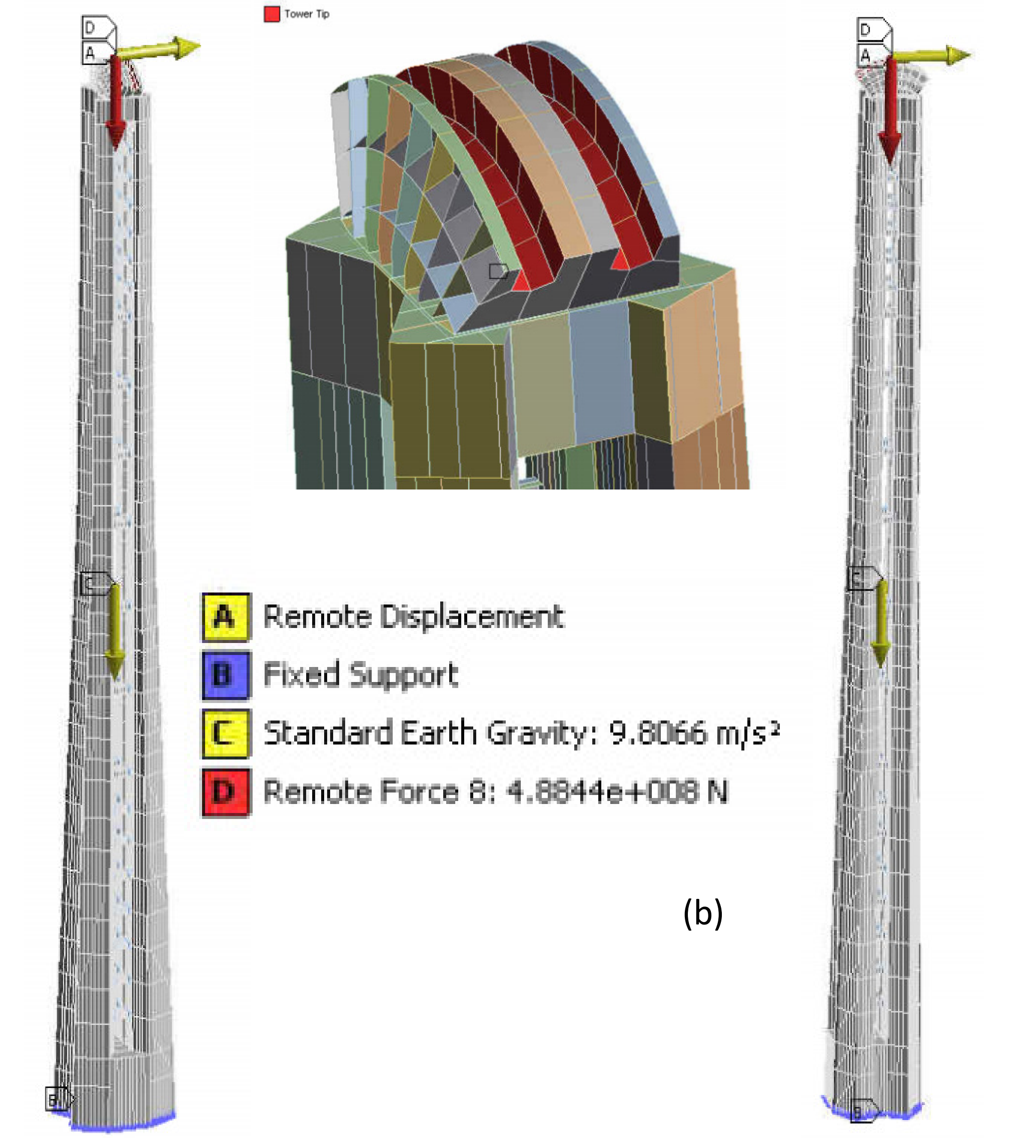





20

Assumptions

- Tower base is perfectly fixed to the base plate which sits on the steel/concrete composite pile cap,

- Possible effects of deck impacting the tower legs are not included due to presence of gap between the deck and the tower legs.



Transverse Push-Over

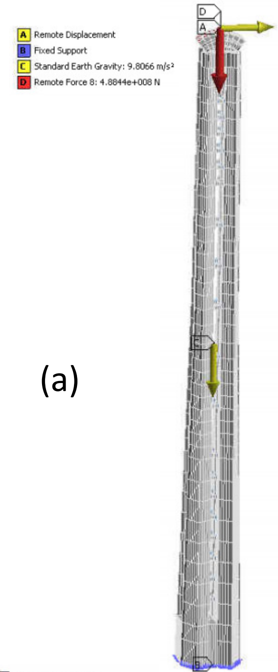
Longitudinal Push- Over

Analysis Settings

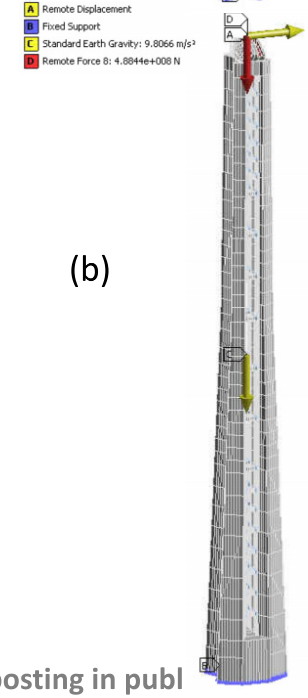
- **Gravity:**
  - **Standard gravity (self-weight of tower)**
  - **Single concentrated force at tower tip (vertical component of cable force from whole bridge gravity analysis)**

- **Lateral Force: <u>single incremental displacement is applied at the saddle level</u> (displacement control)**
  - **(a) Longitudinal direction (b) transverse direction**
  - **The cable force at the saddle level is the main driving force of the motion of the tower**
  - **effectiveness of analysis convergence**

- **All force/displacement are applied by remote point**



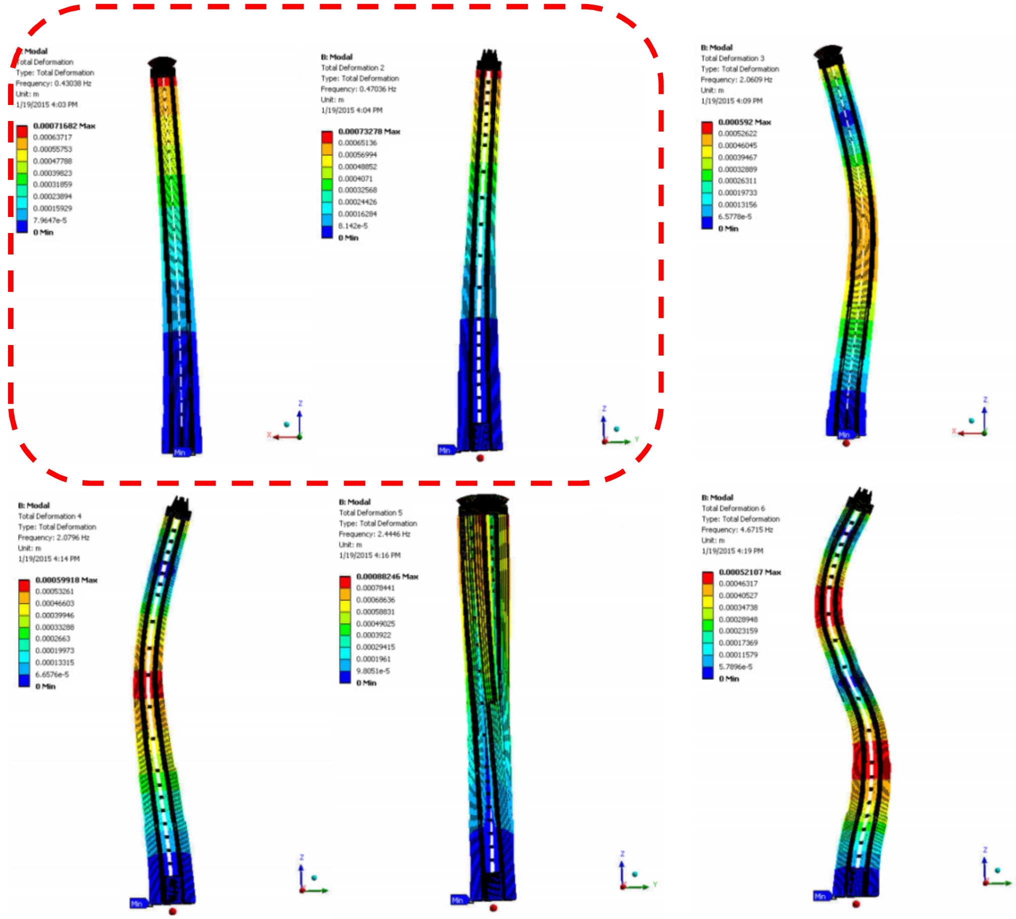
(a)



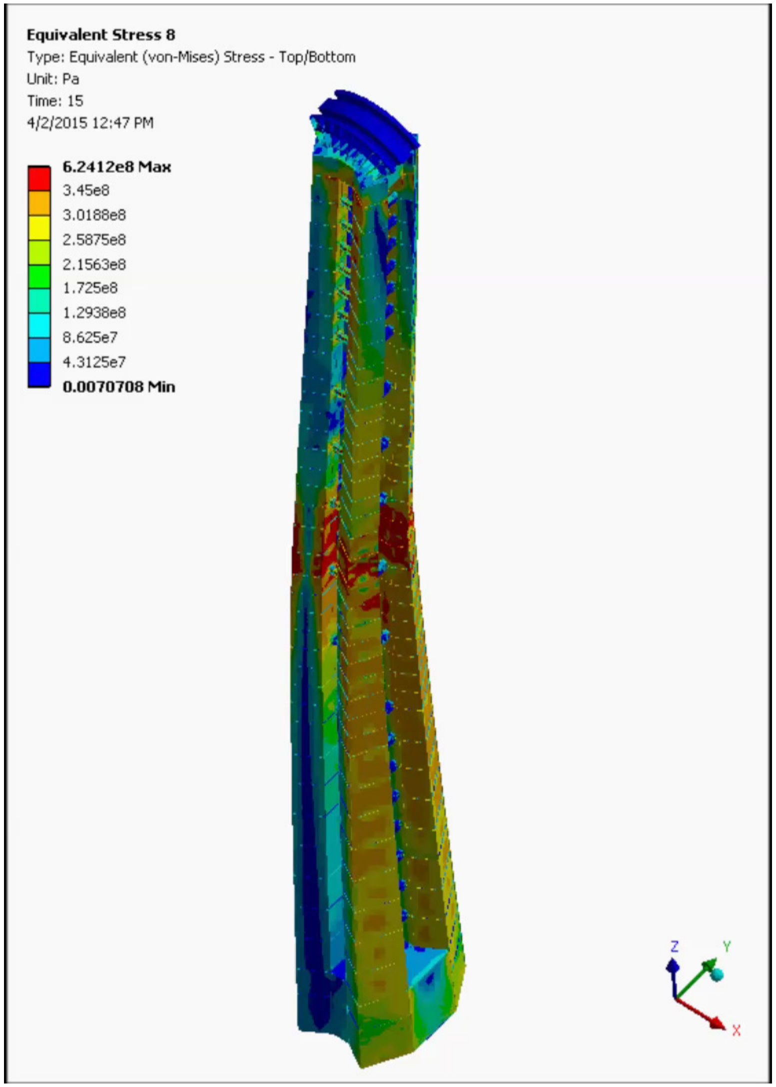
(b)

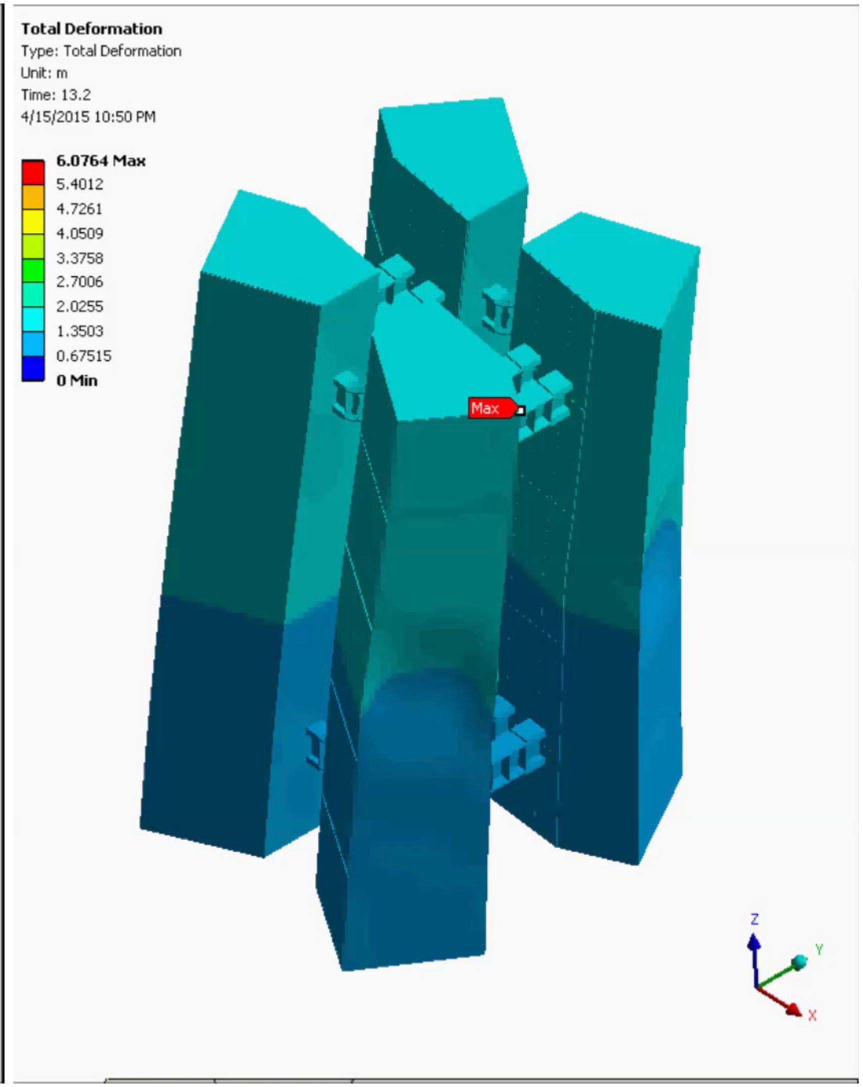
Model Analysis
- tower self-weight only

mode	freq(Hz)	Period(s)	Effective mass ratio (X)	Effective mass ratio (Y)
1	0.43038	2.323528	**0.5048**	**0.0000**
2	0.47036	2.126031	**0.0000**	**0.4875**
3	2.0609	0.485225	**0.2129**	**0.0000**
4	2.0796	0.480862	**0.0000**	**0.2130**
5	2.4446	0.409065	**0.0000**	**0.0000**
6	4.6715	0.214064	**0.0000**	**0.0902**
7	4.7441	0.210788	**0.0852**	**0.0000**
8	5.9063	0.169311	**0.0000**	**0.0000**
9	7.7604	0.128859	**0.0000**	**0.0372**
10	8.1032	0.123408	**0.0000**	**0.0000**
11	8.1405	0.122843	**0.0396**	**0.0000**
12	9.3183	0.107316	**0.0000**	**0.0000**
13	10.993	0.090967	**0.0000**	**0.0282**
14	11.467	0.087207	**0.0291**	**0.0000**
15	13.355	0.074878	**0.0000**	**0.0000**
16	13.956	0.071654	**0.0000**	**0.0000**
17	13.957	0.071649	**0.0000**	**0.0000**
18	13.957	0.071649	**0.0000**	**0.0000**
19	13.959	0.071638	**0.0000**	**0.0000**
20	14.134	0.070751	**0.0000**	**0.0137**



Video of von Mises Stresses Longitudinal Pushover

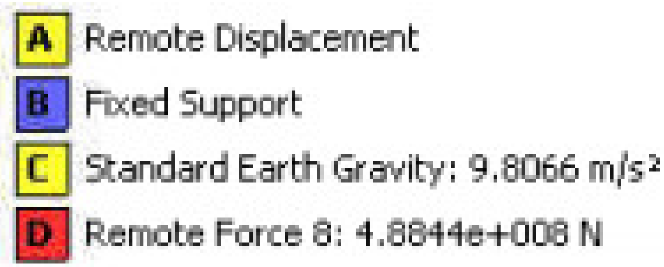


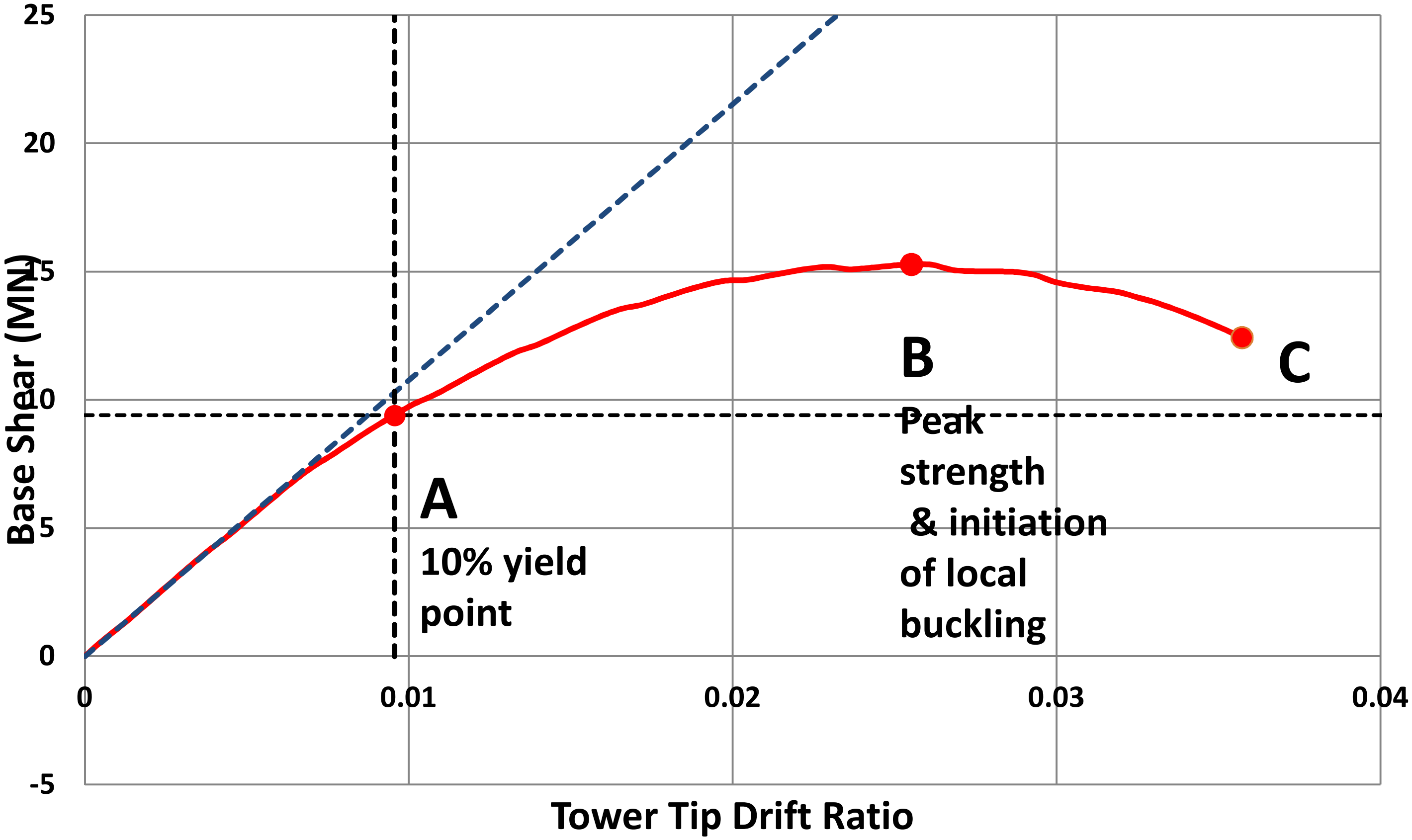


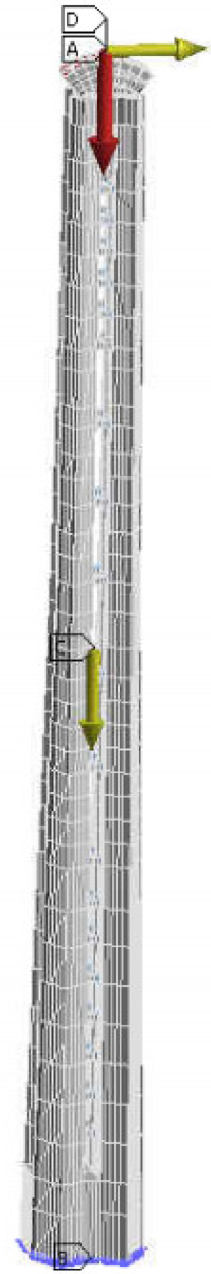
ANSYS

Longitudinal
Pushover curve

Pushed by **single displacement** at tower tip



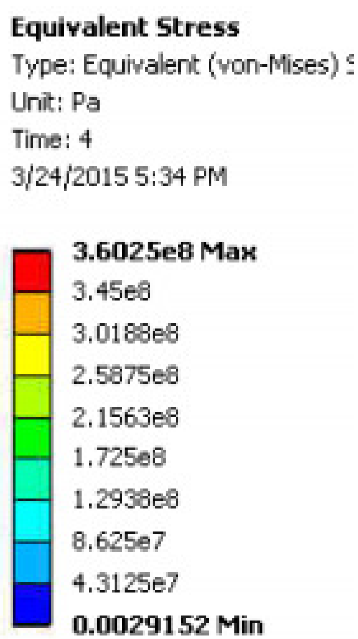


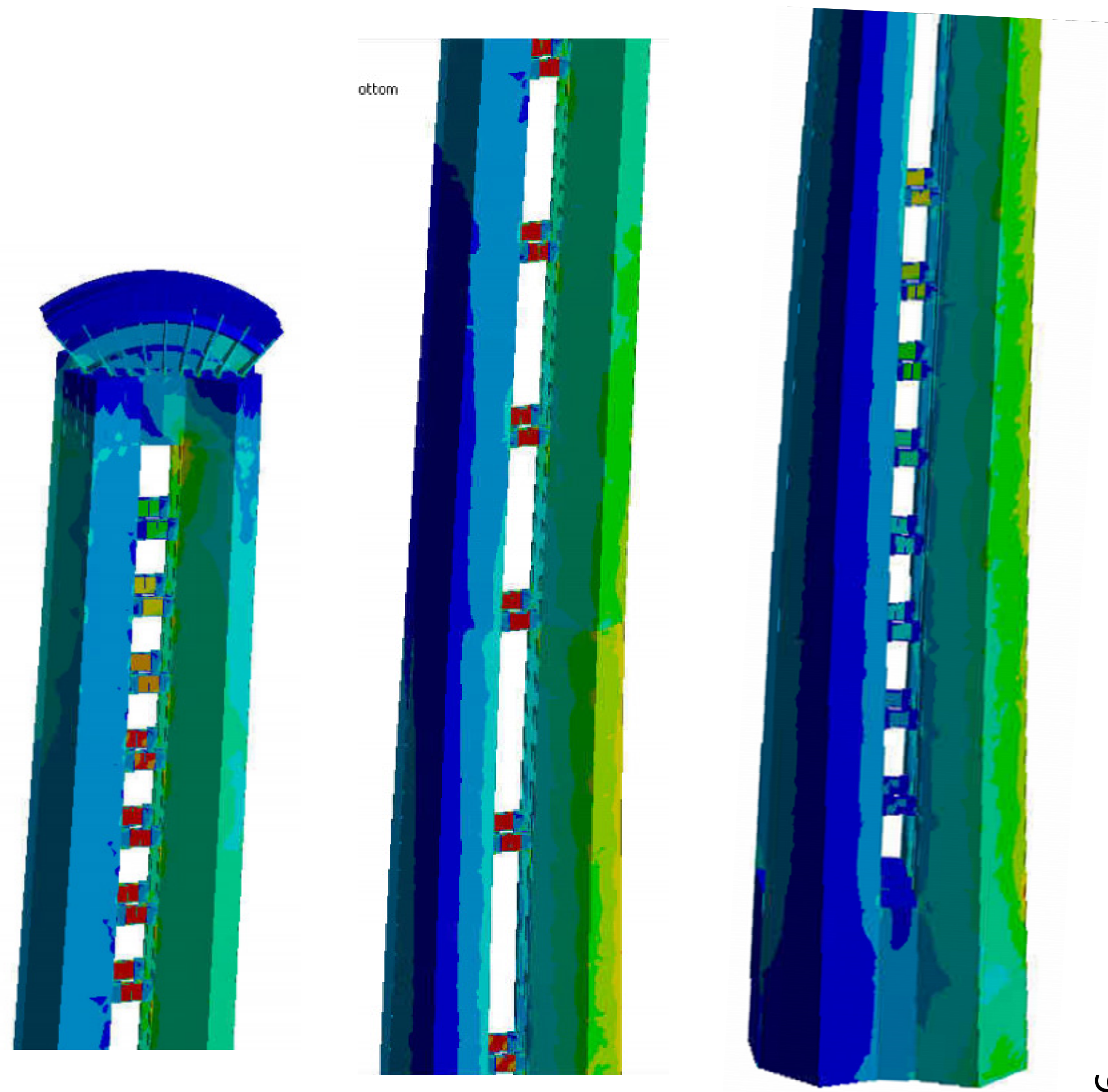


Longitudinal Pushover

The von Mises Stresses
at Point A (10% Yield Point)

Shear Links have yielded in the upper and middle segment of the tower but not in the bottom segment

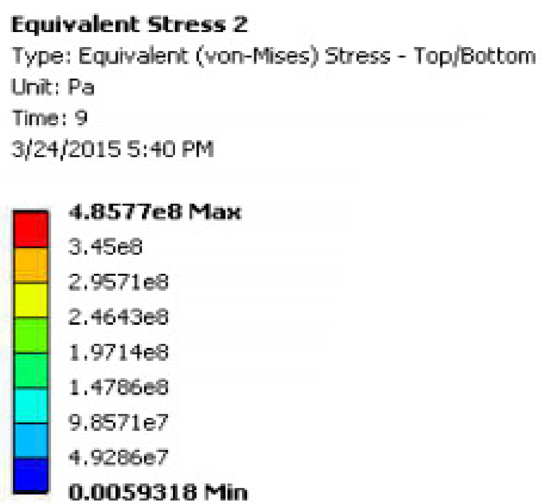


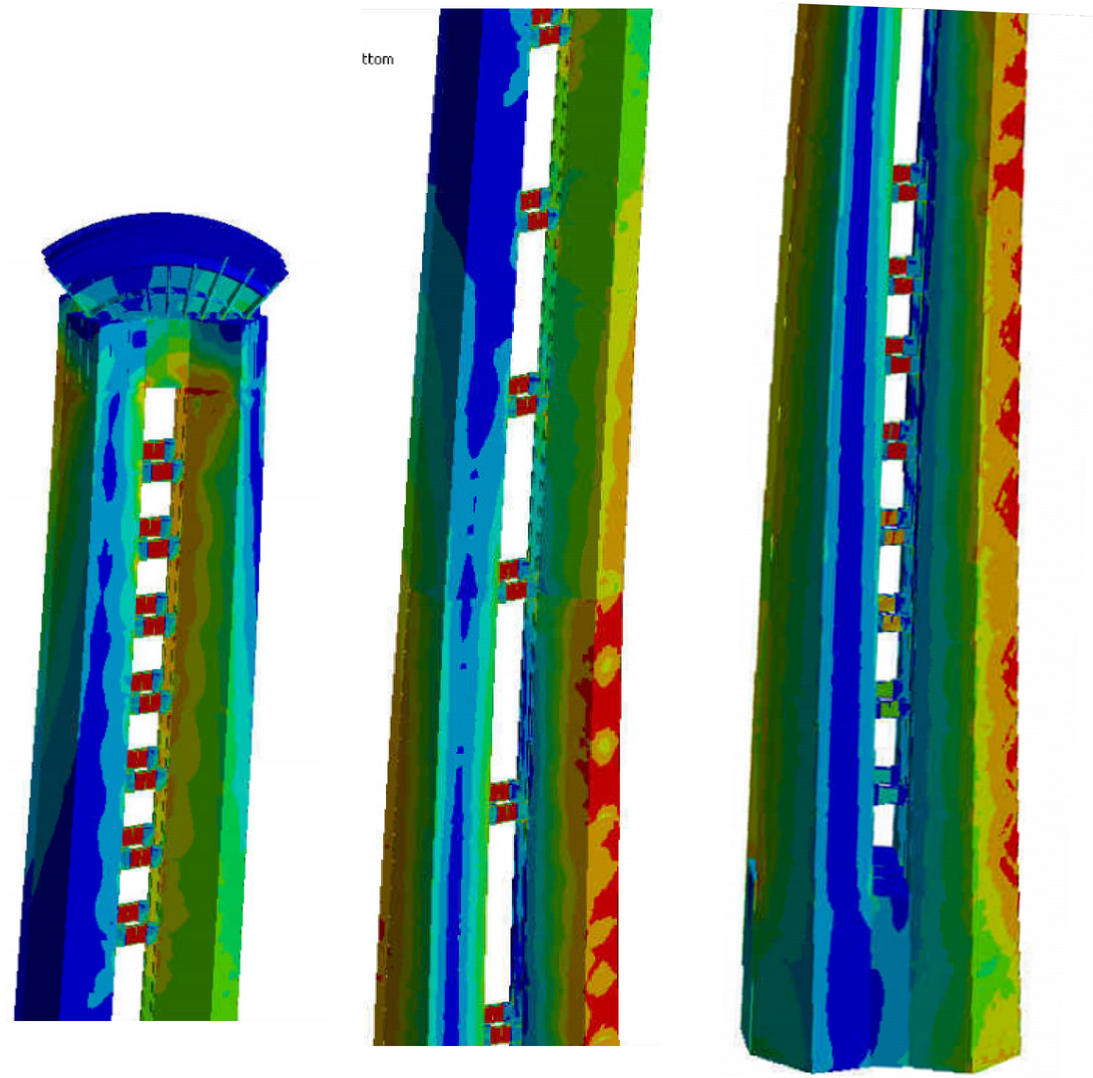


The von Mises Stresses at Point B (Maximum Strength Point)

Longitudinal Pushover

Shear Links continued to yield and those in the bottom segment also yielded.
Severe yielding of tower legs in compression and yielding of tension side as well.

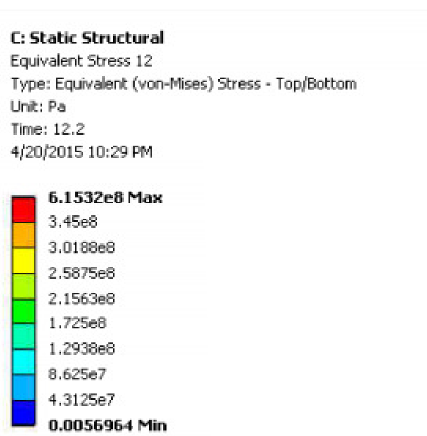


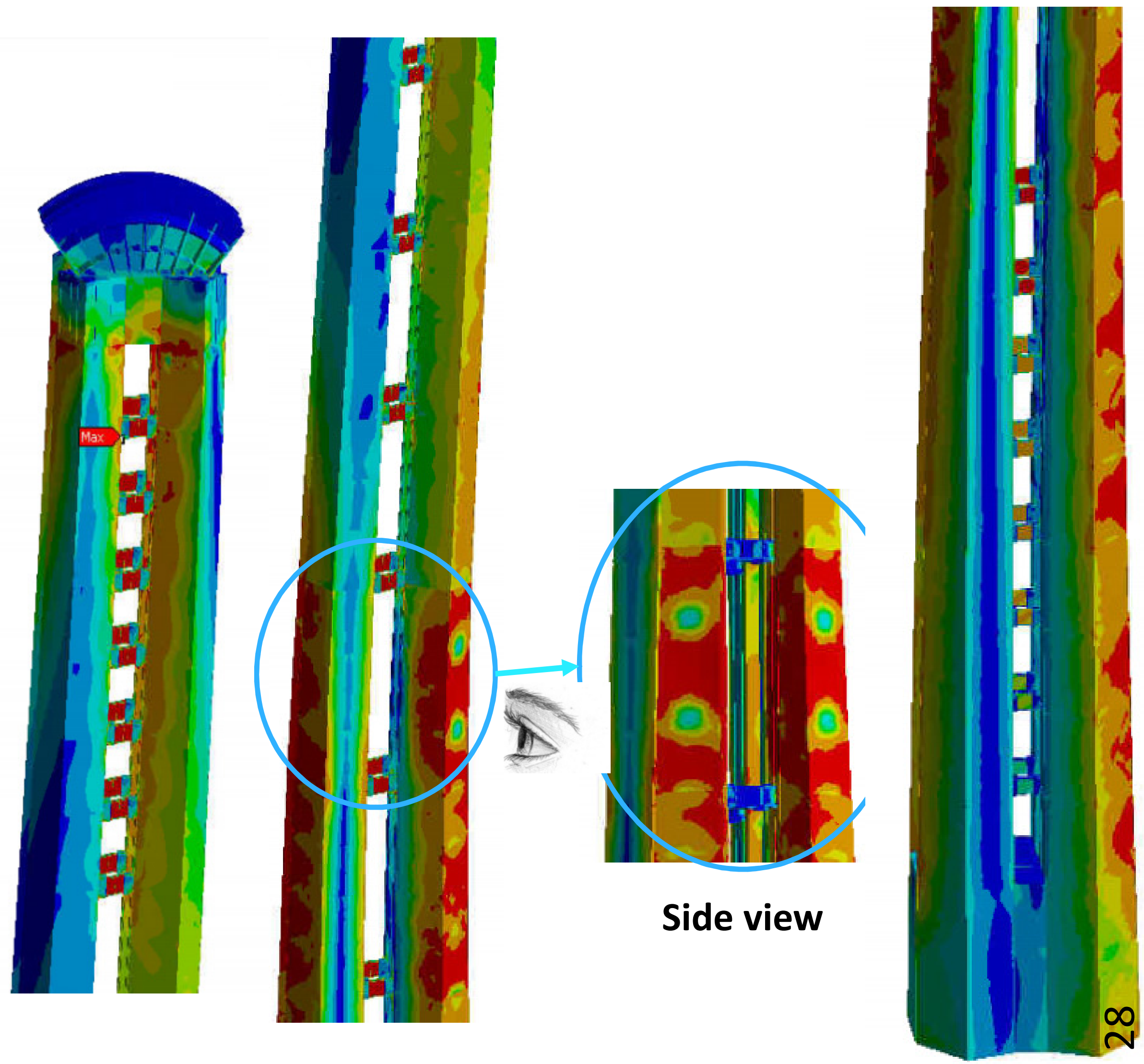


The von Mises Stresses at Point C (Point where strength dropped)

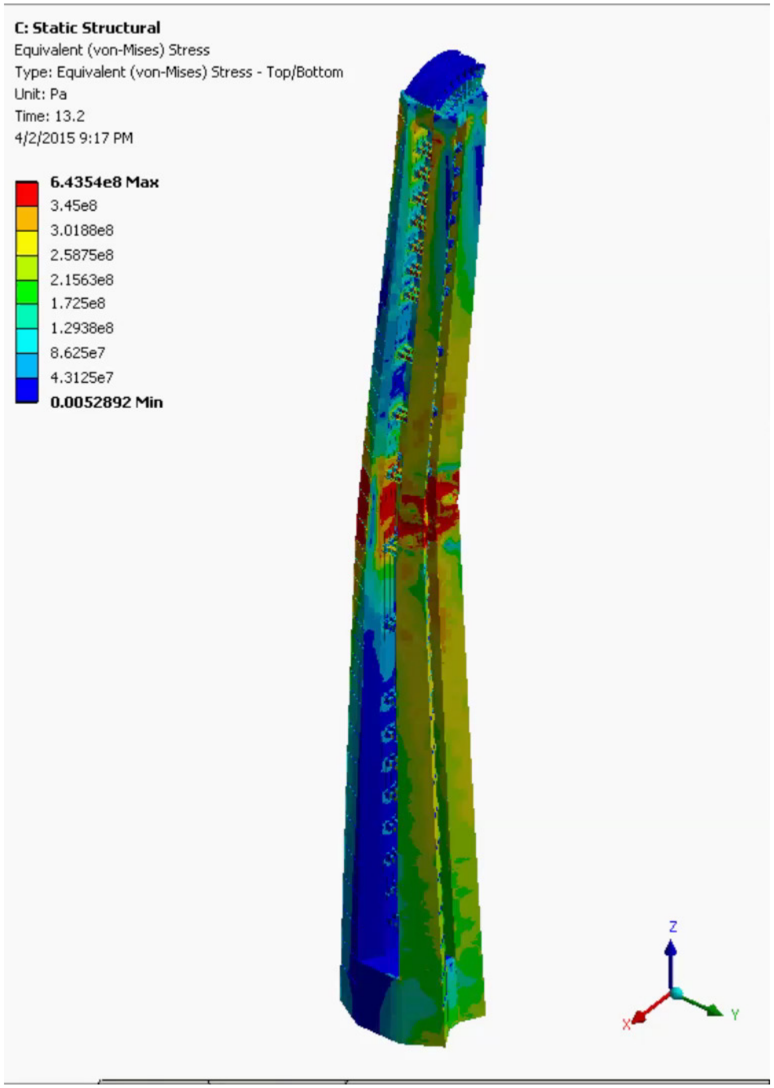
Longitudinal Pushover

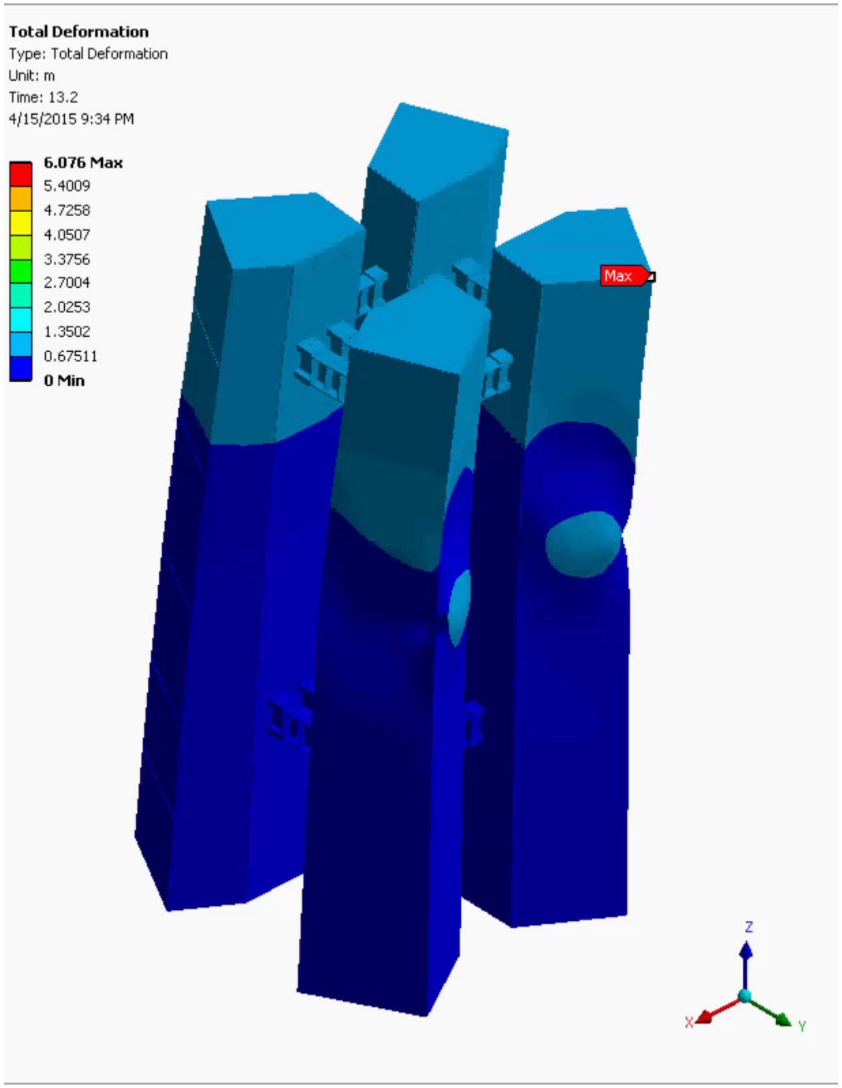
Severe local buckling in the compression side of tower leg and severe tension yielding of tension side of tower leg.
Yielding under saddle grillage. Equivalent plastic strain in the shear links is about 0.10.





Video of von Mises Stresses Transverse Pushover

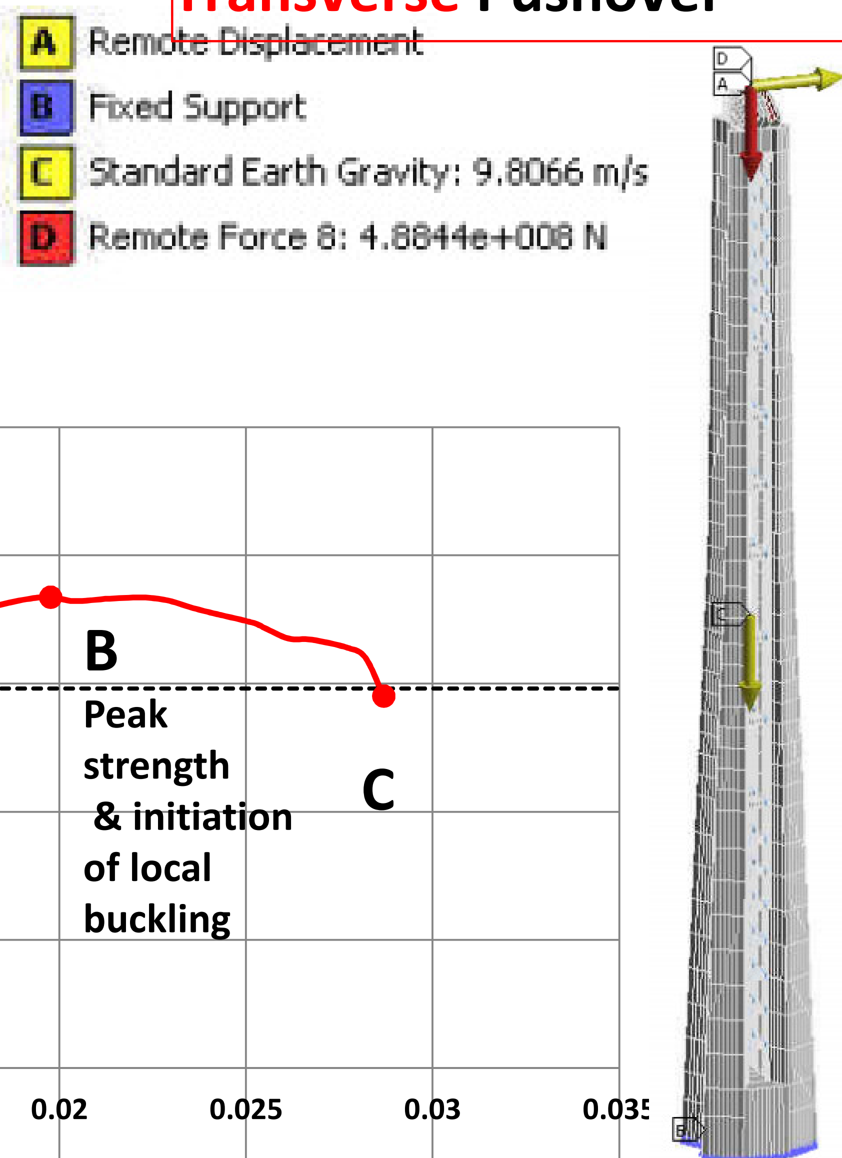


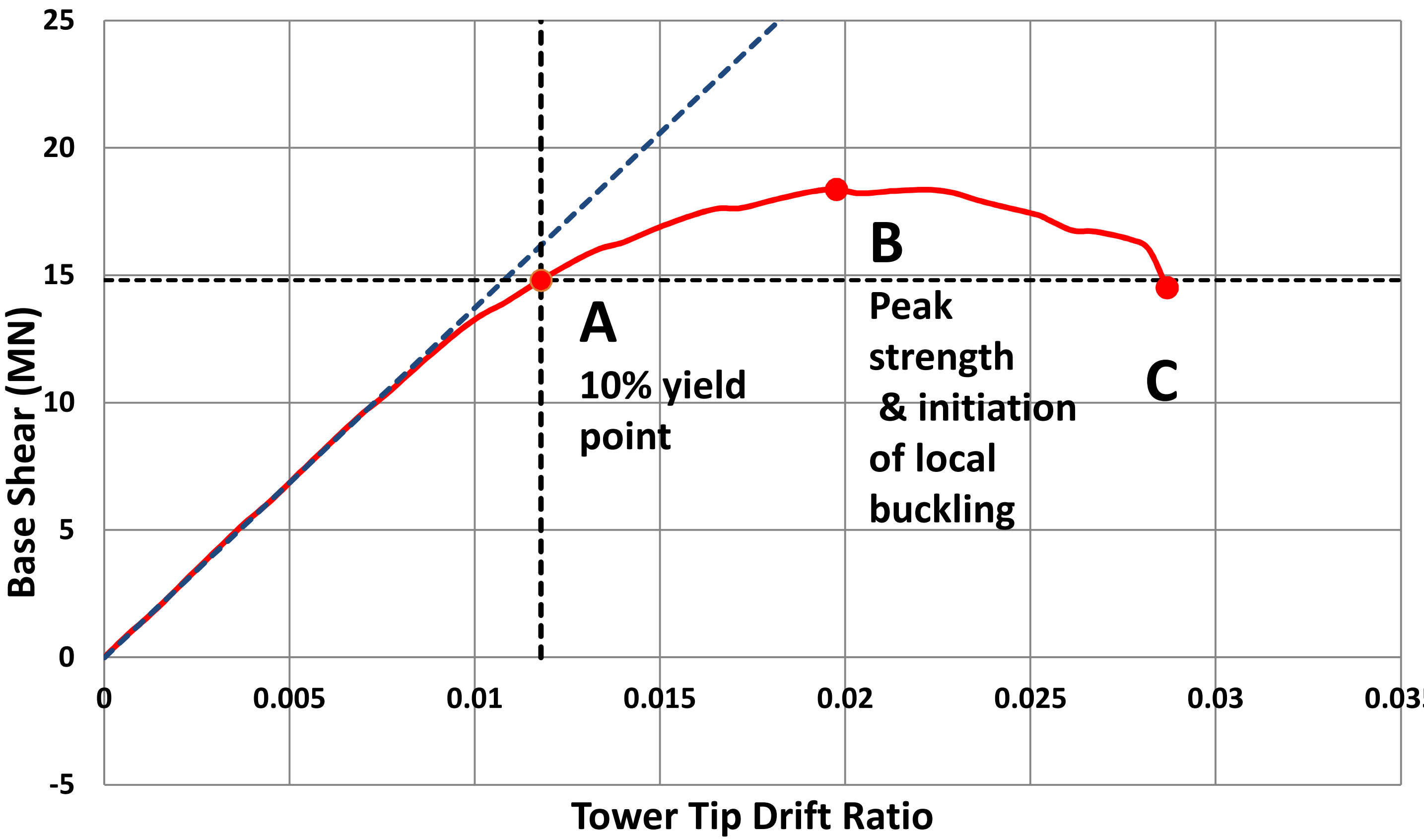


Transverse Pushover curve

Push by **single displacement** at tower tip

Transverse Pushover

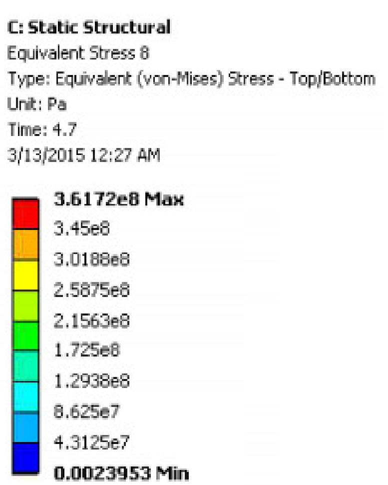


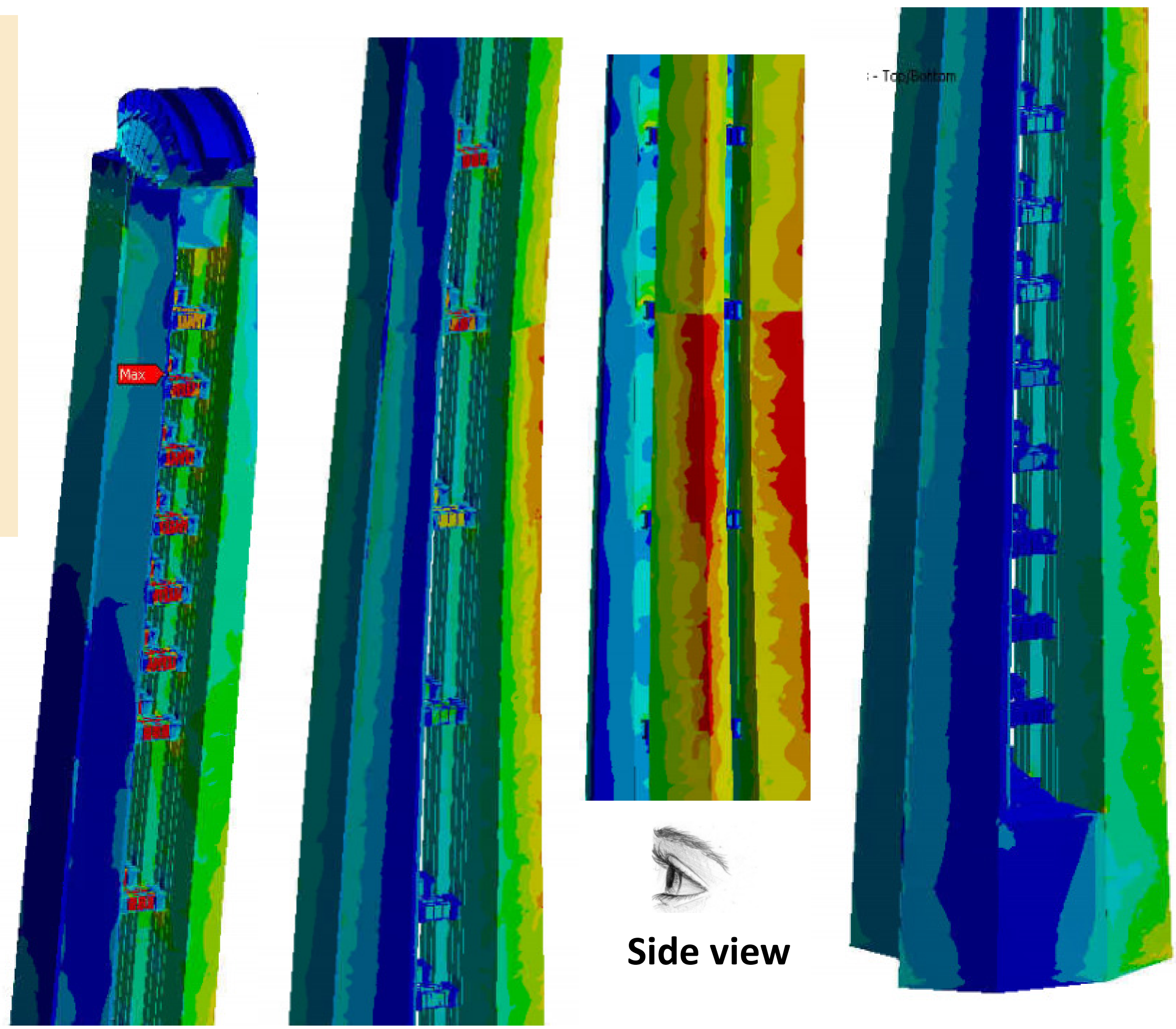


The von Mises Stresses at Point A (10% Yield Point)

Transverse Pushover

Shear Links have yielded in the upper and middle segment of the tower but not in the bottom segment.
Compression legs have yielded severely on compression side.

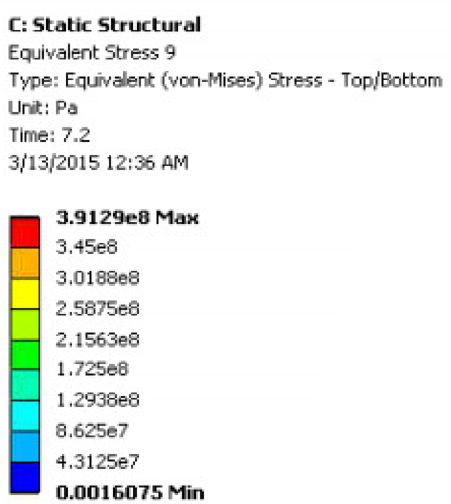


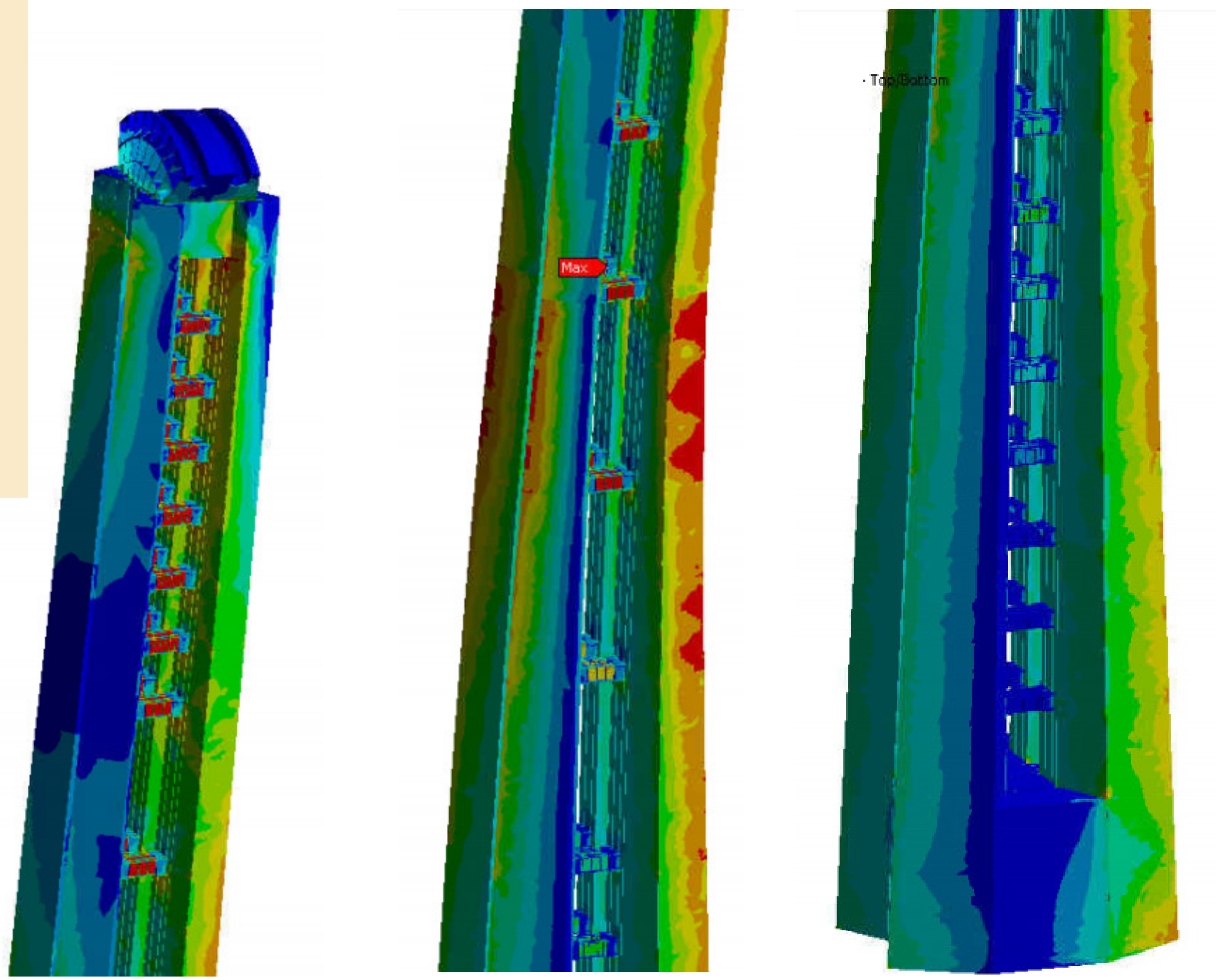


The von Mises Stresses at Point B (Maximum Strength Point)

Transverse Pushover

Shear Links continued to yield but those in the bottom segment did not develop much yielding. Severe yielding of tower legs in compression and yielding of tension side as well.

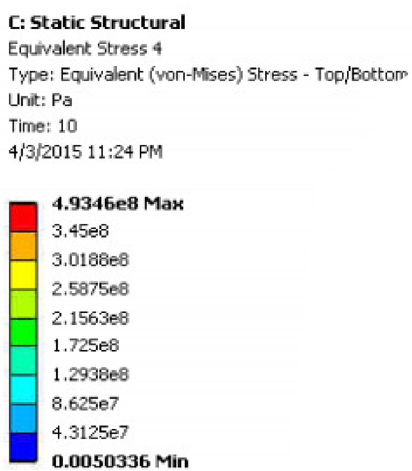


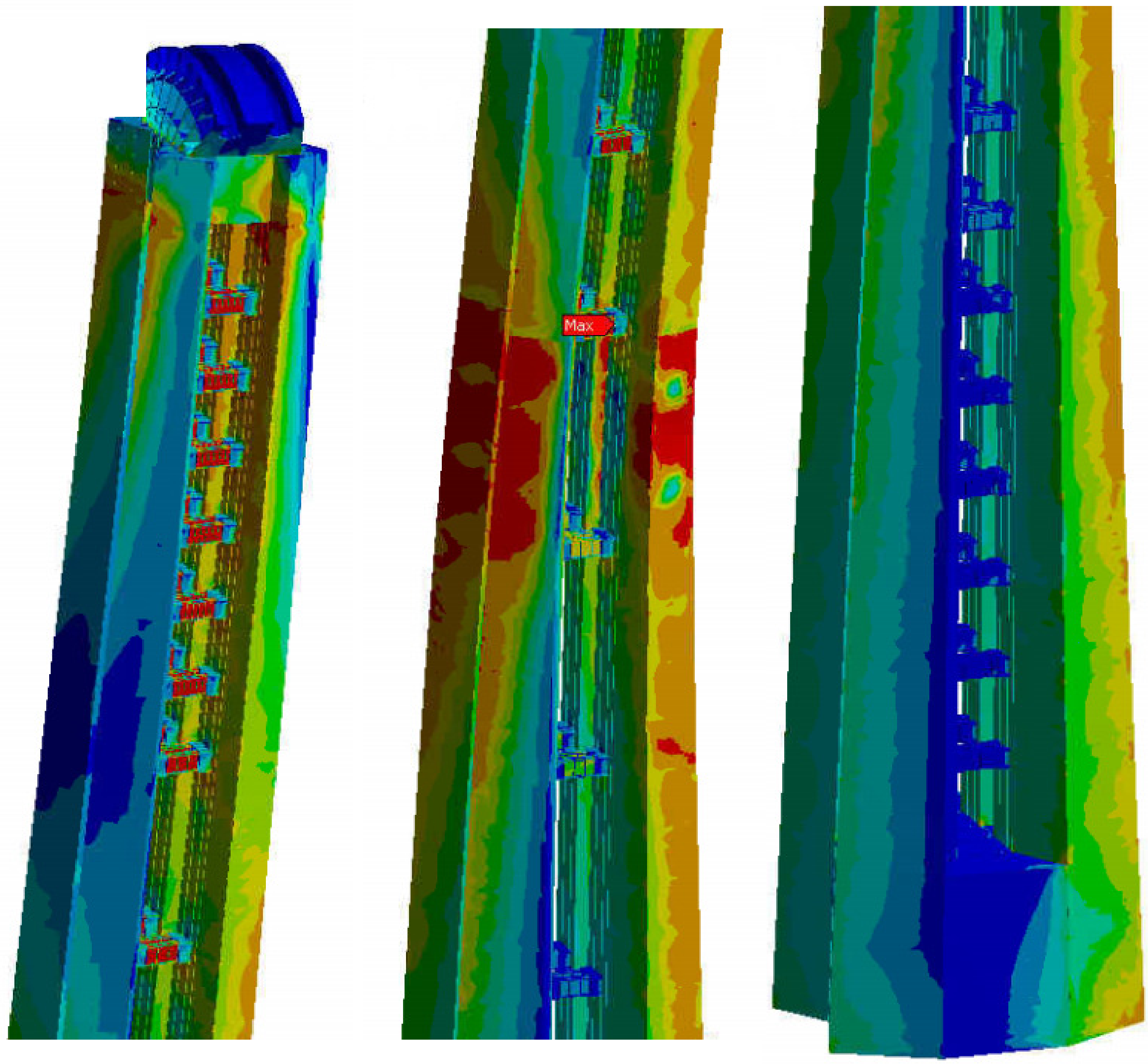


Transverse Pushover

The von Mises Stresses at Point C (Point where strength dropped)

Severe local buckling in the compression side of tower leg and severe tension yielding of tension side of tower tension leg. Yielding under saddle grillage. Equivalent plastic strain in the shear links is about 0.10.





Concluding Remarks

1. We found that ANSYS v15.0 was capable of capturing the material and geometric nonlinearities (e.g. buckling) of the complex structure of the tower of the Self-Anchored Suspension Bay Bridge, the subject of this study

2. We were satisfied with the user friendliness of the pre- and post-processing & the powerful meshing capability

3. We are now starting to use the sub-modeling and fracture mechanics feature to predict possible fracture of the net section at the tension side

4. We found that, contrary to designers' assertion, the tower shear links are not the only yielding element of the tower during earthquakes, but the tower legs experience significant buckling, permanent distortion in compression and significant yielding in tension of strains up to about 0.1.