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

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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

(a) Build Towers and Anchor Blocks

(b) Add Main Cables

(c) Add Suspenders and Roadway

(d) Bridge is Complete
Examples of Construction of Typical “Ground-Anchored” Suspension Bridges Around the World

West spans of the Bay Bridge

Great Belt, Denmark

Akashi-Kaikyo, Japan

Golden Gate
Construction of a “Self-Anchored” Suspension Bridge

(a) Build Tower, Build Temporary Support Structure
(b) Build Roadway, Add Cables
(c) Connect Cables to Deck, Add Suspenders
(d) Remove Support Structure
Example of “Self-Anchored” Suspension Bridge

Large Compression in the Deck

Very large Forces in the deck

The New SAS Bay Bridge
(Subject of these studies)

Yeongjong Grand Bridge, S. Korea

Konohana Bridge, Japan
The Self-Anchored Suspension Bay Bridge
The Self-Anchored Suspension Bay Bridge
Tower and Typical Tower Cross Section

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
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

Ref: M. Nader and B. Maroney
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

Transverse

Longitudinal
Material Model

All material of tower legs and shear link is Grade 50 steel with $F_y$ (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
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:** single incremental displacement is applied at the saddle level (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
## Model Analysis
- tower self-weight only

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Video of von Mises Stresses Longitudinal Pushover
**Longitudinal Pushover curve**

Pushed by **single displacement** at tower tip

![Graph showing base shear (MN) vs. tower tip drift ratio.]

- **A** indicates the 10% yield point.
- **B** marks the peak strength and initiation of local buckling.
- **C** denotes the point of significant drift.

**Support Conditions:***
- **A**: Remote Displacement
- **B**: Fixed Support
- **C**: Standard Earth Gravity: 9.8066 m/s²
- **D**: Remote Force 8: 4.8844e+008 N
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 A (10% Yield Point)
The von Mises Stresses at Point B (Maximum Strength Point)

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.
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](image-url)

- **A** Remote Displacement
- **B** Fixed Support
- **C** Standard Earth Gravity: 9.8066 m/s
- **D** Remote Force: 4.8844e+008 N

**Graph Details:**
- **Base Shear (MN)**
- **Tower Tip Drift Ratio**

- **A** 10% yield point
- **B** Peak strength & initiation of local buckling
- **C**
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. Compression legs have yielded severely on compression side.
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.

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