

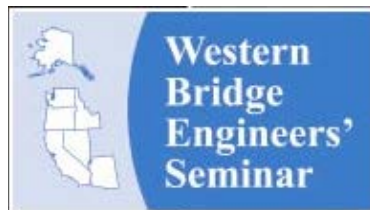
# Tower Erection Engineering for the New San Francisco-Oakland Bay Bridge Self-Anchored Suspension Span

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# Presentation Overview

- 1) Project, SAS T1 Tower and Erection Introduction
- 2) T1 Erection Tower Design
- 3) T1 Erection Sequence Analyses
- 4) T1 Pull Back Analyses
- 5) Summary

# 1. Project Background

- Located in San Francisco Bay, California
- The east and west spans of the self-anchored portion of the bridge is 385m and 180m respectively.
- It is the largest of its kind in the world.



# 1. Project Background – Cont.

- The single 160m high T1:
  - Consists of four shafts, each made of four field spliced segments.
  - Weighing up to 1100 tonnes and have a max. segment height of 48m.
  - The four shafts are interconnected by shear link beams and cross braces.
  - Tower capped by connection grillage and cable saddle.

# 1. Project Background – cont.

- The temporary T1 Erection Tower (T1ET) incorporated a lifting gantry.
- 164m tall, chevron-braced steel structure built around the T1 Tower.
- T1ET supports a lifting gantry system and a self-climbing crane (FAVCO Tower) which was used to construct T1ET.







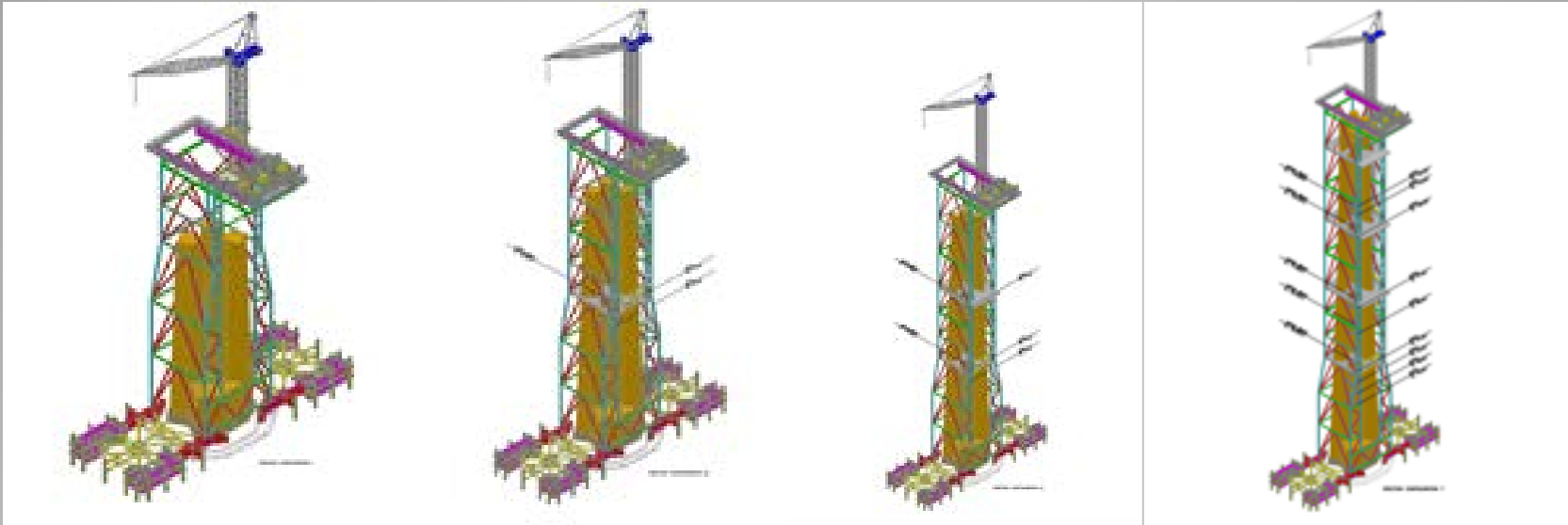


## 2. T1 Erection Tower

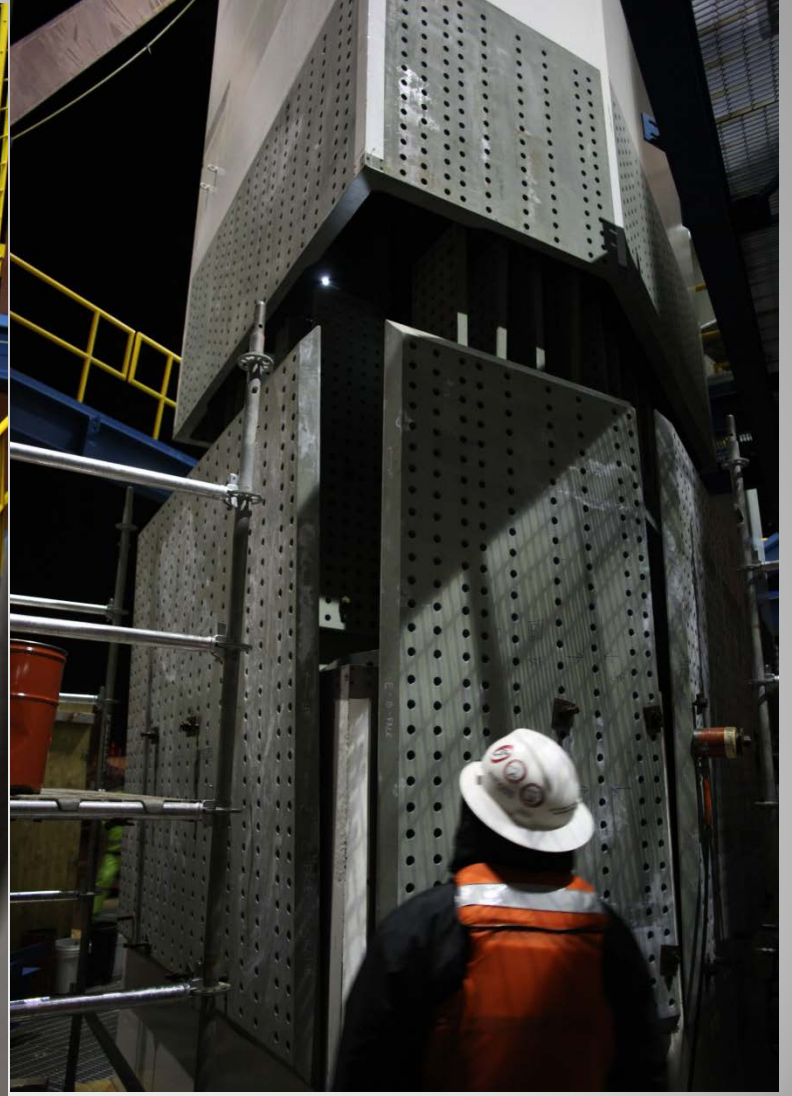
- T1ET was constructed to provide schedule flexibility for the erection of the T1 Tower segments, the temporary trusses and OBG Lifts.
- Four major construction stages Tower segment Lifts 1 thru 4
- Strand jack lifting capacity 1320 tonnes.
- Work platforms provided at the four T1 shaft field splice elevations; platforms provide a diaphragm and brace T1ET to the permanent T1 Tower.
- T1 provides T1ET's main lateral support system.



## 2.1. T1ET Design



- Designed for 25 year wind load
  - 100mph 3-second gust at El. 50 m.
- The wind tunnel study indicated drag coefficients 20%-30% lower than ASCE 7.

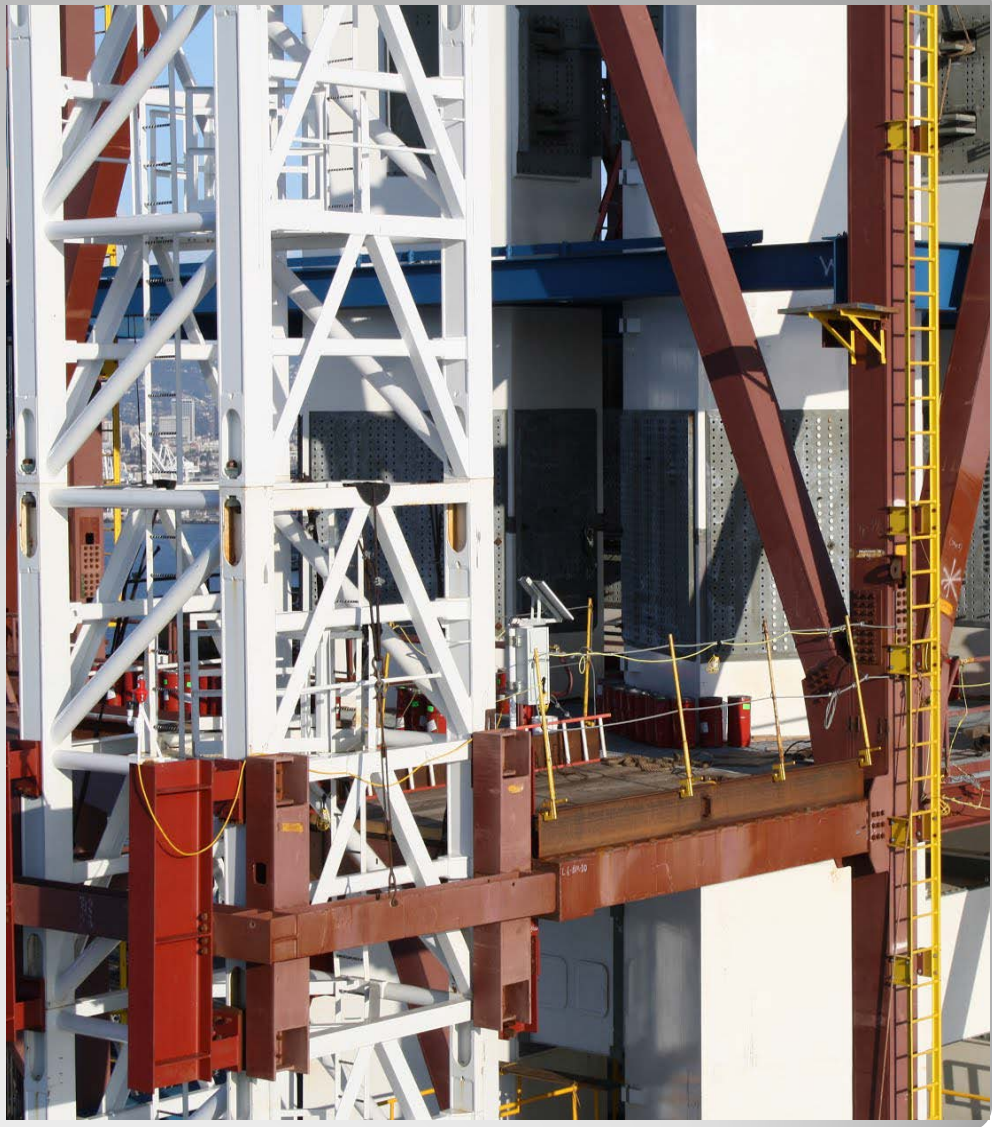


- Analyses results indicated that prior to Lift 1, T1ET vertical bracings were quite sensitive to the stiffness of the pile group foundation of T1 Tower on which it was constructed.
- After the splice platform constructed, the T1ET design was governed by the T1 lifting loads.

## 2.2. FAVCO Crane Tower

- The FAVCO crane tower was used to construct T1ET, and has four major configurations, corresponding to the T1 Tower Lifts.
- The FAVCO crane tower consisted of 27 individual 4m tall sections, 18 of which were reinforced.
- The FAVCO base was supported by T1ET at El. 59 m.
- Reviewed mode shapes and periods to ensure no “modal coupling”. ( minimum mode separation of 25%)

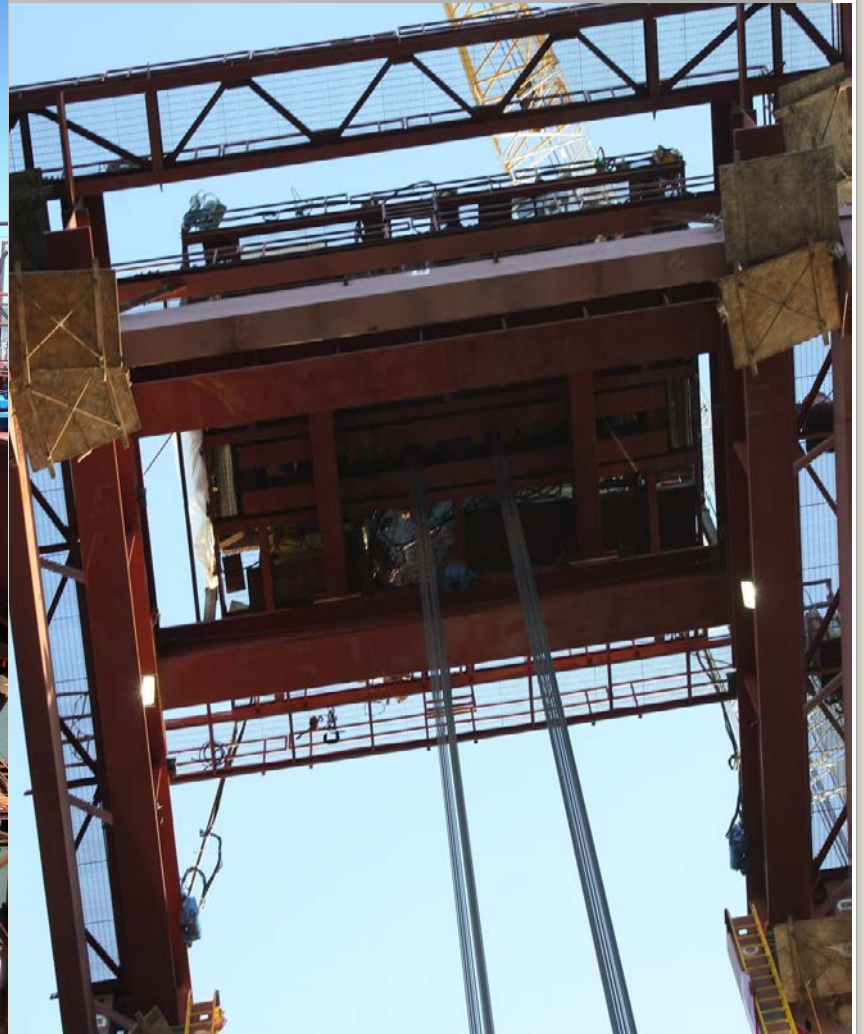
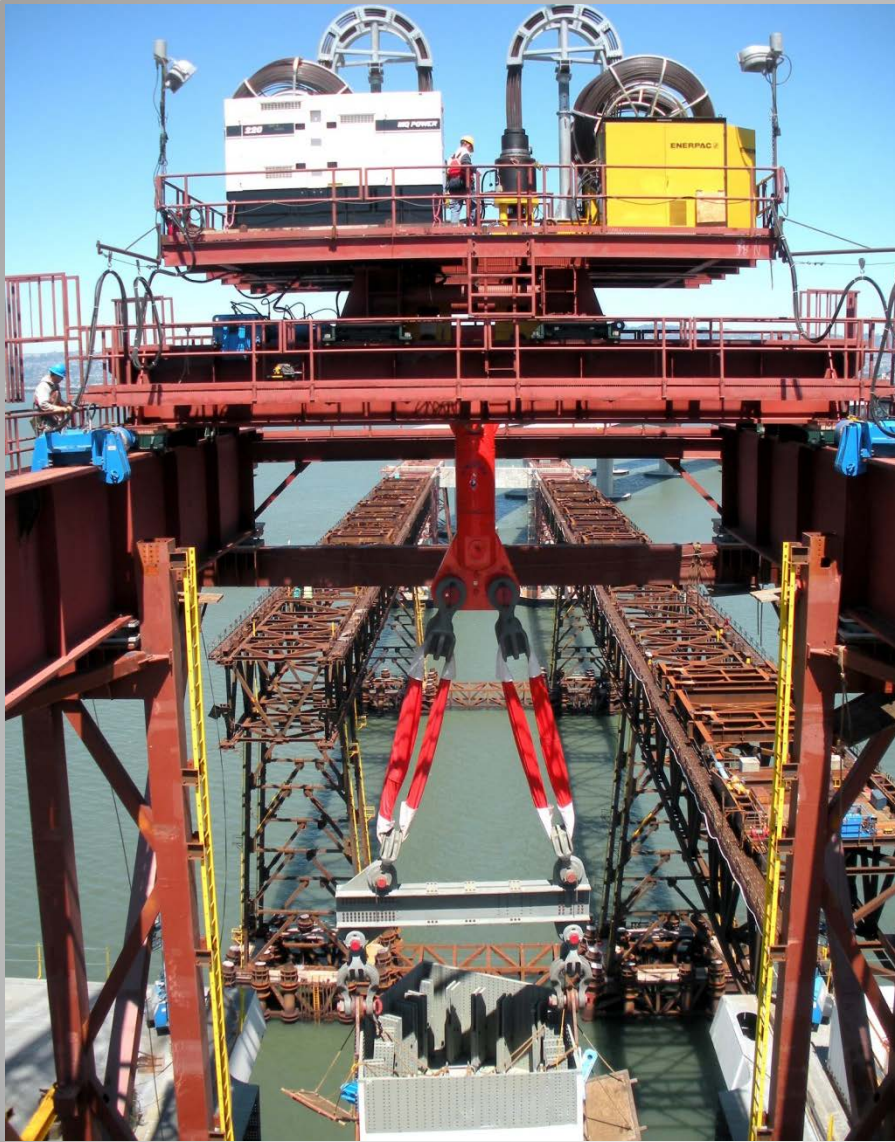






## 2.3 Lifting Gantry System

- Designed for lifting permanent T1 Tower columns into position.
- The gantry has three tiers of beams. The top tier is oriented in the north-south direction and supports two 660-metric-ton strand jacks.
- The middle tier is oriented in the east-west direction and is supported on Hillman rollers to allow north-south translation of the T1 Lifts.
- The bottom tier is oriented in the north-south direction and will also roll on Hillman rollers on the gantry runway girders to translate the T1 Lifts.



### 3. T1 Erection Sequence Analyses

- Four major stages.
- Challenges: compact working area, tight bolting clearances, and tight construction schedule
- Detailed erection analysis and bolt-up procedures.
- The following aspects were investigated:
  - The demands at the T1 Tower base and splices;
  - The demands for the shear link beams and crossbraces in each stage;
  - The thermal deflection of the tower shafts at each stage;
  - The loads imposed from T1ET to the T1 Tower through the splice platforms

## 3.1. Tower Shaft Field Splices

- 400 splice plates
- 28,240-M27 A490M bolts and vary in length between 200 and 280mm. In total there are 87,208 bolts in the four field splices.
- After the shafts were set in place, the field splices were bolted in phases to allow construction to advance.
- The analyses indicated that approximately 10% of the splice bolts needed to be tightened to seismically secure the partially erected tower, and to allow further erection and bracing of the temporary T1ET.

## 3.2. Shear Link Beams and Crossbraces

- Following the alignment of tower shafts, the four independent tower legs are interconnected by two structural components – the shear link beams and the crossbraces.
- The shear link beams join the four shafts at 20 tower elevations. The crossbraces join the shafts at eight elevations.
- The shear link beams are designed to act as yielding fuses to dissipate the energy in a major seismic event before the tower shafts experience any damage.



- Iterative analyses were performed to develop the optimal bolting sequence of the shear links.
  - Specific shear links were to be fully bolted prior to beginning erection of the next stage. (Remaining shear links were bolted at later time) - off of the critical path.
- During the erection, the shear links may have been overloaded under seismic load: T1 Tower shafts were free-standing, and a minimum of shear links fully installed.
- The contractor chose to accept responsibility for replacing overloaded shear links if an earthquake occurred during this relatively short exposure period.

## 3.3. Tower Geometry Control

The contract tolerance: vertical to within 1:2500.

- Thermal load effects investigated
- the site engineer was able to gauge the required jack stroke necessary to bring the shaft into alignment.
- Based on the in-place survey at the top of lift 4, the tower center line was vertical to within 1:5385 and within 8mm of design elevation.

## **3.4. Loads Imposed from T1ET**

- The T1 Tower provides lateral support for T1ET through the splice platforms at various elevations. It is critical to ensure that the maximum load imposed on T1 Tower skin plate from the T1ET through the elastomeric pads at each splice platform will not overstress the permanent components.

## 4. T1 Pull Back Analyses

- To facilitate the installation of the main cable
- T1 Tower and tower saddle were deflected 550mm to the west.
- Allowed the balancing of the horizontal force components of the free hanging during transfer of the deck dead load to



## 5. Summary

- T1ET used successfully to erect the T1 tower.
- Erection sequence analysis established minimum bolting requirements to keep to tight schedule
- Unique tie-back cables simplified main cable erection to correct geometry following load-transfer



# Acknowledgements

