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Design of Chacao Bridge – Lessons learned

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Teknologidagene 01.11.2018

Chacao Bridge - Introduction

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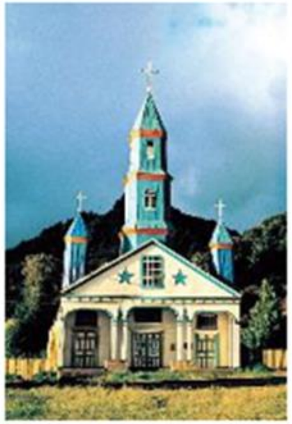
Chacao Bridge - Introduction

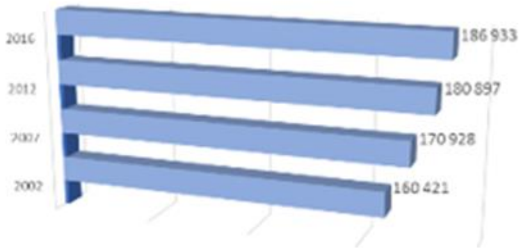
The fishing villages

The wooden churches



« Zorro de Darwin »

The 186 933 population (2016)



The ferries

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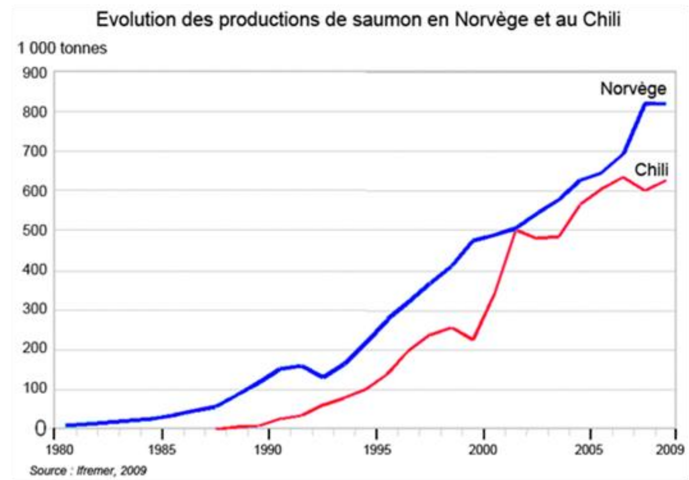
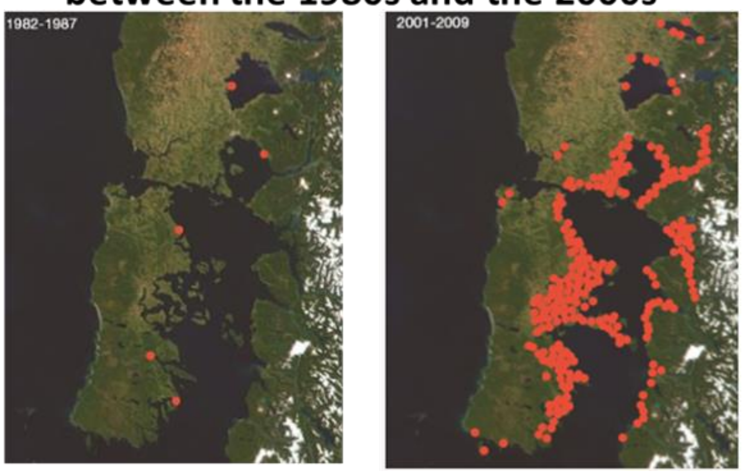
Chacao Bridge - Introduction

2nd largest producer after Norway

But stabilization of production in 2007 due to a health problem



Evolution of the number of salmon farms between the 1980s and the 2000s



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Chacao Bridge - Introduction

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Chacao Bridge – History and status

Client/Owner: MOP

Contract: DB

Awarded: 2014

Contractor: CPC (Consorcio Puente Chacao)

Construction commencement: 2017

Finished: 2023

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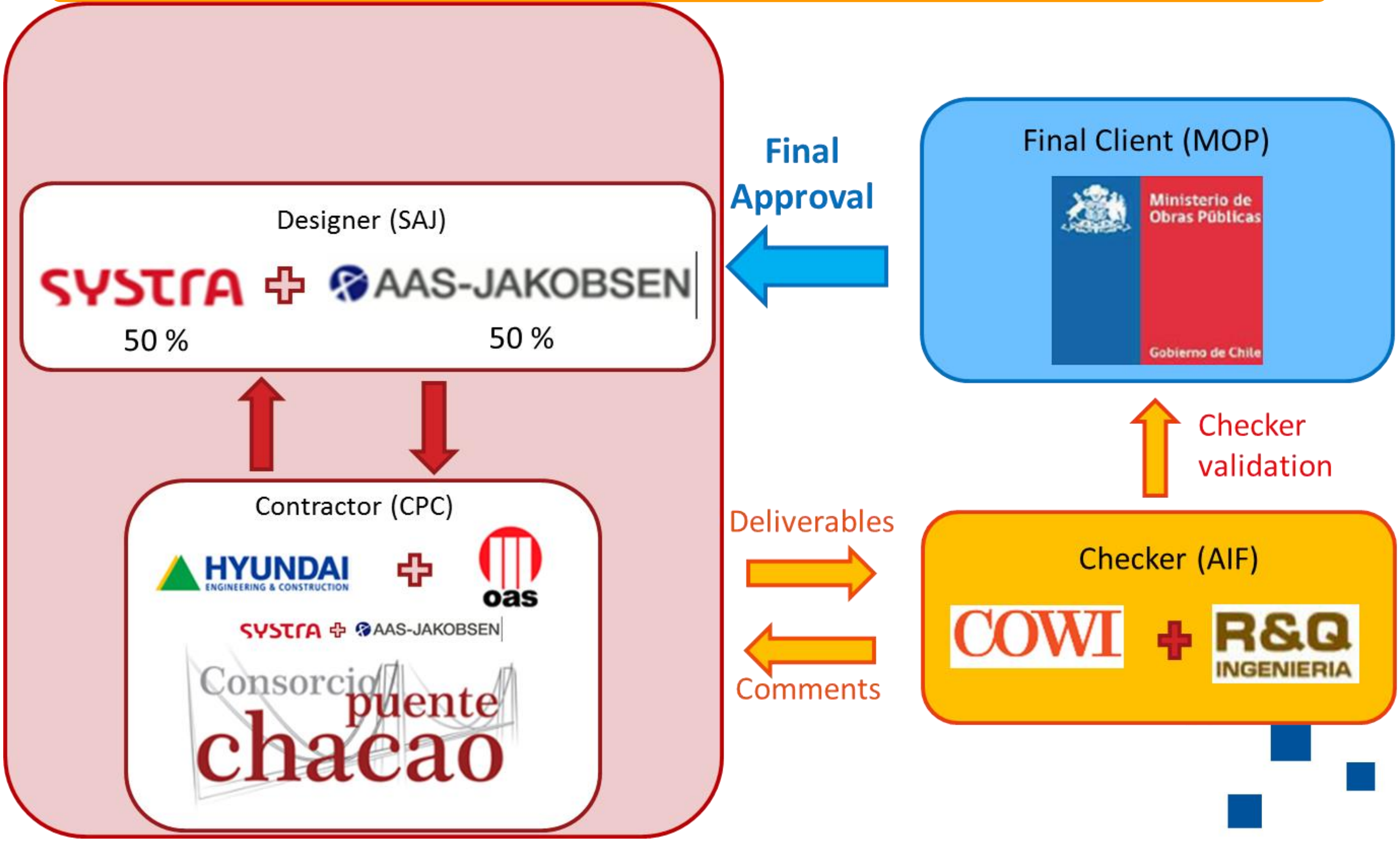
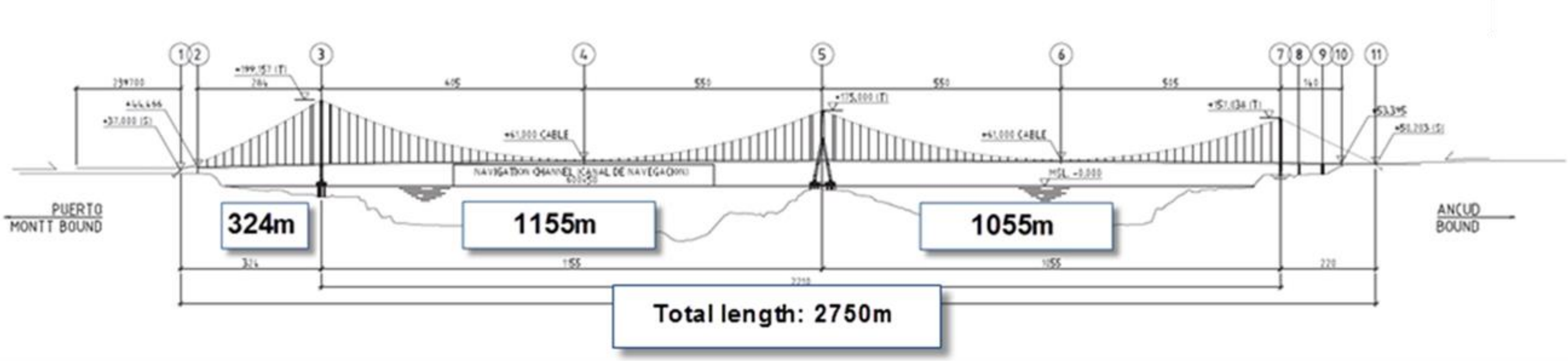
Chacao Bridge - Organization



Chacao Bridge - General



- Suspension bridge: 2 main spans and one suspended side span in North
- Approach bridge South: 220m
- 3 pylons: 199m, 175m, 157m
- Navigational clearance: 600x50m

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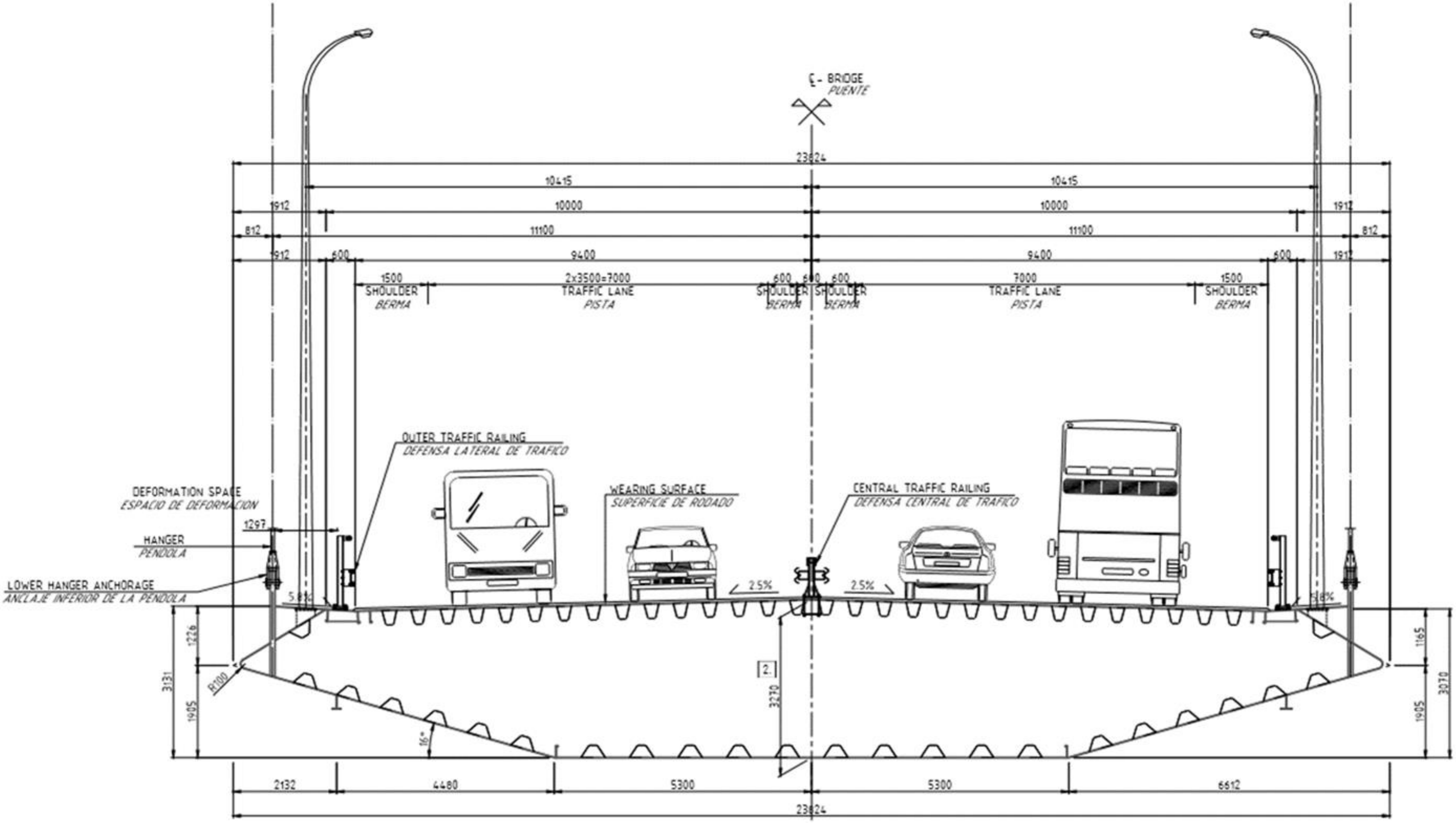
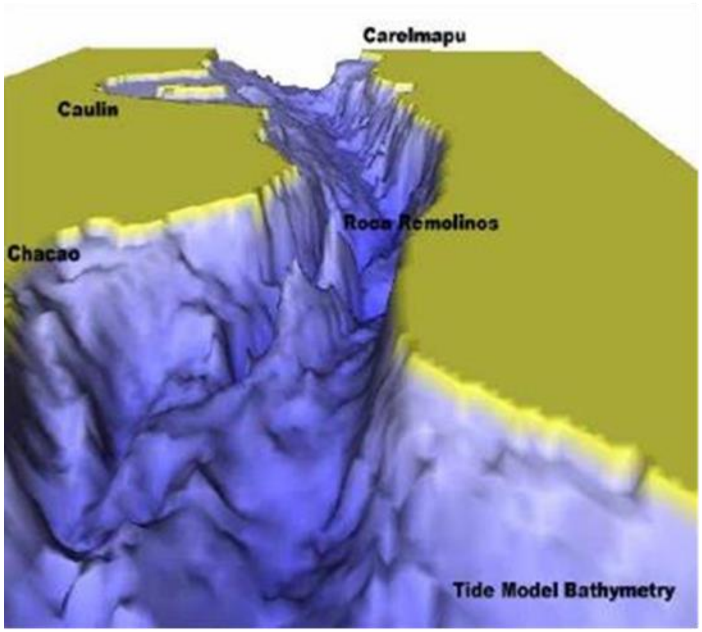
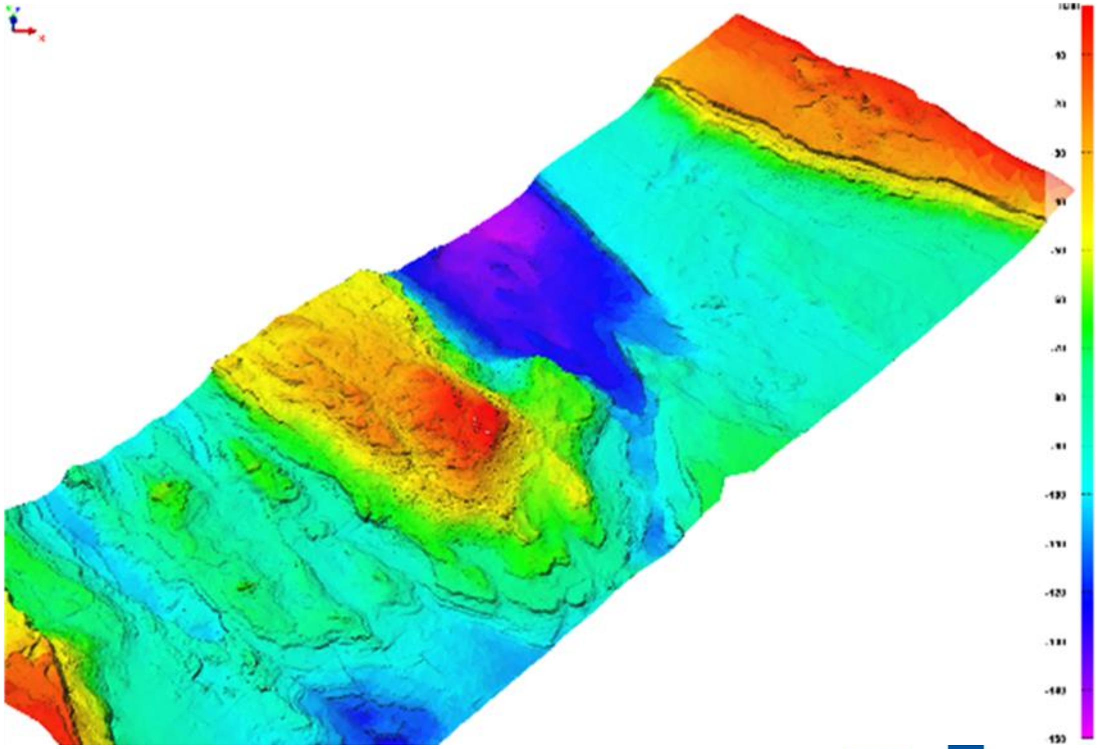
Chacao Bridge - General



Chacao Bridge - General

- Chacao Bridge is a link between Chiloé Island and Chile mainland
  - Chanel depth can reach 120 meters along bridge axis
  - Central Pylon founded on Roca Remolinos in the middle of Chacao Chanel





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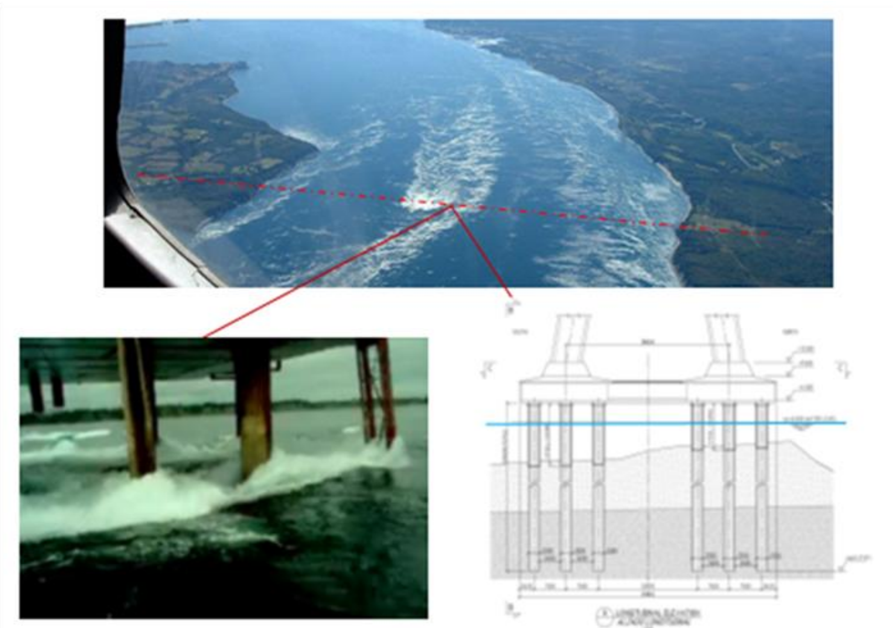
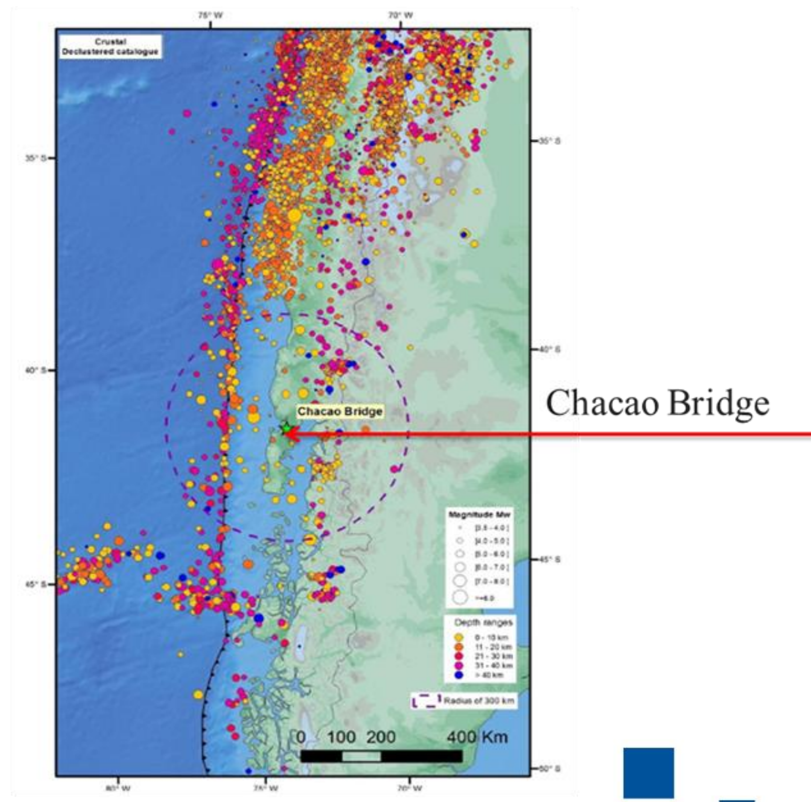
Environmental conditions

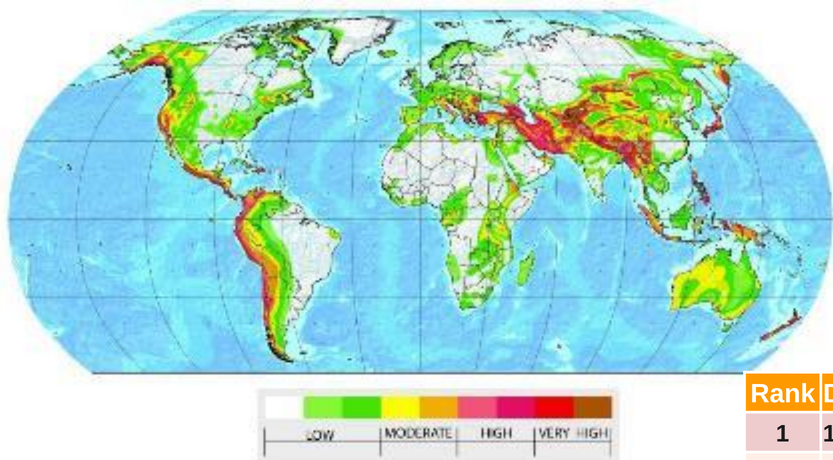
- Strong winds
- Strong currents
- High seismicity including Tsunami





Chacao Bridge – Environmental conditions

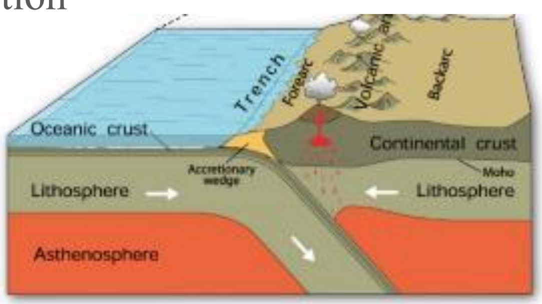
Chacao Bridge is located in one of the most important seismic area in the world



- 3 of the 12 major seismic events ever recorded occur in Chile

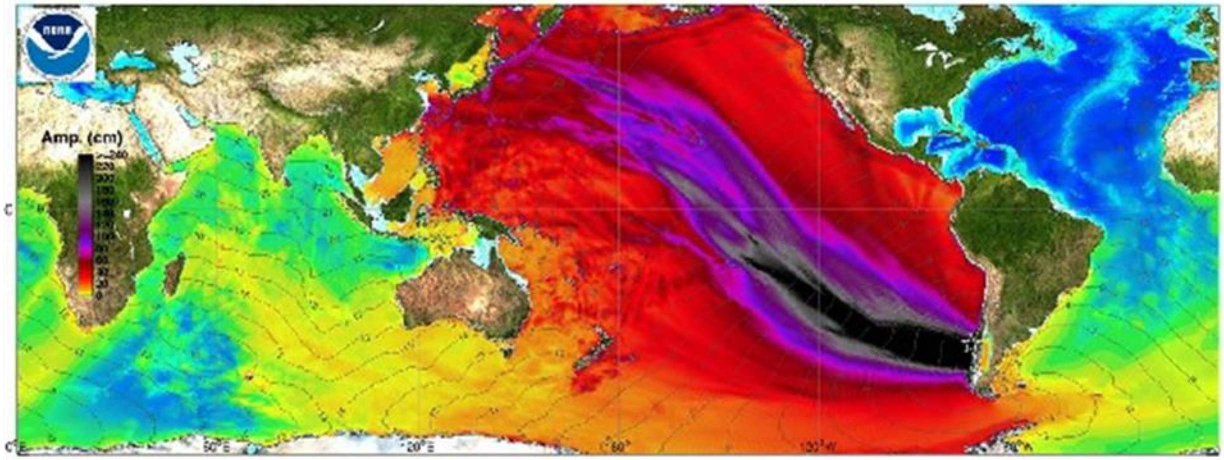
Rank	Date	Location	Country	Magnitude
1	**1960 May 22**	**Valdivia**	**Chile**	**9.6**
2	1964 March 27	Prince William Sound	Alaska, United States	9.2
3	2004 December 26	Sumatra	Indonesia	9.3
4	2011 March 11	Pacific Ocean, Tōhoku region	Japan	9.1
5	1952 November 4	Kamchatka	Soviet Union	9.0
6	**1868 August 13**	**Arica**	**Chile**	**9.0**
7	1700 January 26	Pacific Ocean	USA and Canada	9.0
8	869 July 9	Pacific Ocean, Tōhoku region	Japan	8.9
9	1762 April 2	Chittagong	Bangladesh	8.8
10	1833 November 25	Sumatra	Indonesia	8.8
11	1906 January 31	Ecuador – Colombia	Ecuador – Colombia	8.8
12	**2010 February 27**	**Maule**	**Chile**	**8.8**

- Seismic hazard
  - Subduction
  - Crustal



Chacao Bridge – Environmental conditions

- VALVIDIA EARTHQUAKE 1960
  - Magnitude 9.6
  - Most powerful earthquake ever recorded
  - Cause of a tsunami with waves up to 25m



Plot of the maximum amplitude for the tsunami waves generated by the 1960 Valvidia Earthquake.

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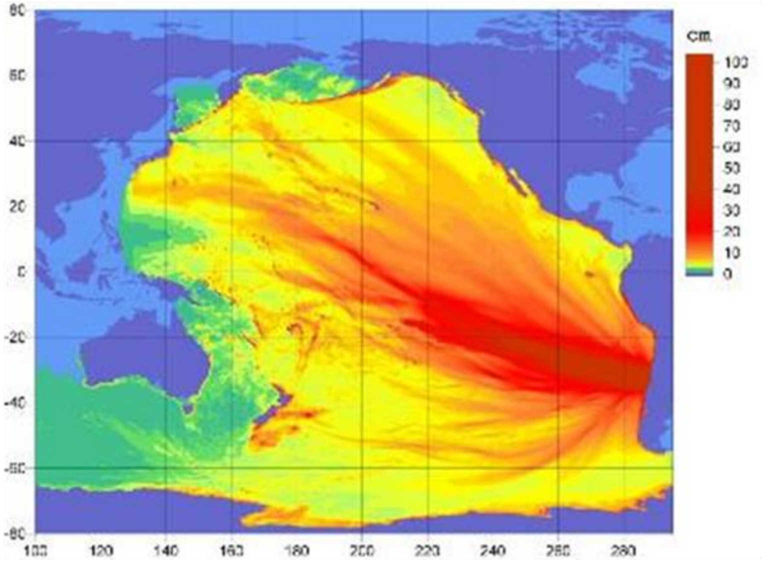
Chacao Bridge – Environmental conditions

- MAULE EARTHQUAKE 2010
  - Magnitude 8.8
  - In the top 12 of the most powerful earthquakes ever recorded
  - Cause of a tsunami with waves up to 10m



Plot of the maximum amplitude for the tsunami waves generated by the 2010 Maule Earthquake.

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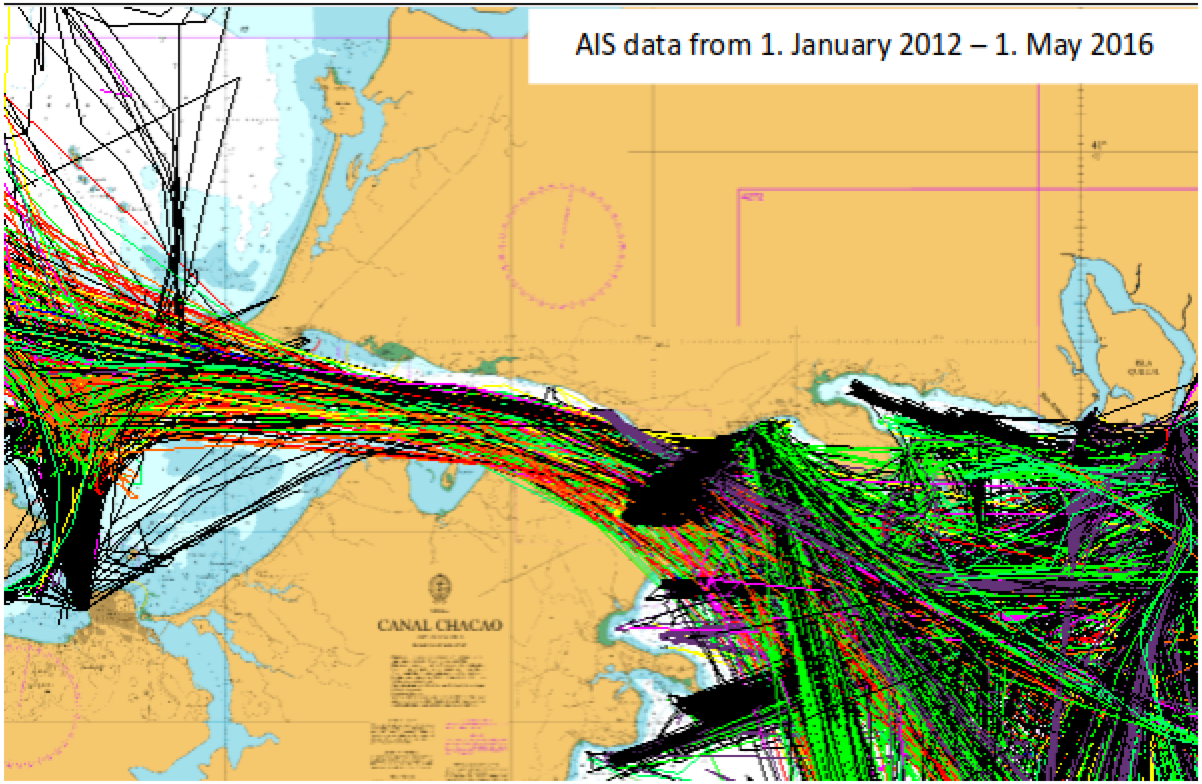
Chacao Bridge – Environmental conditions



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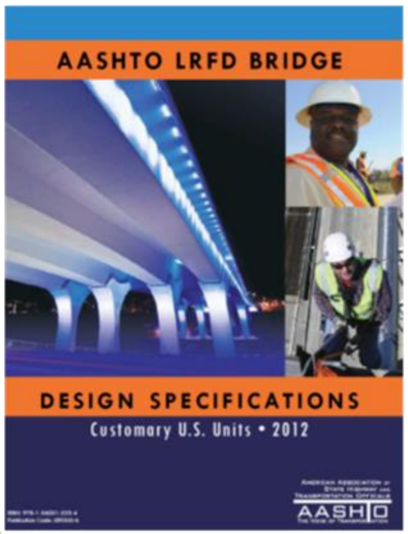
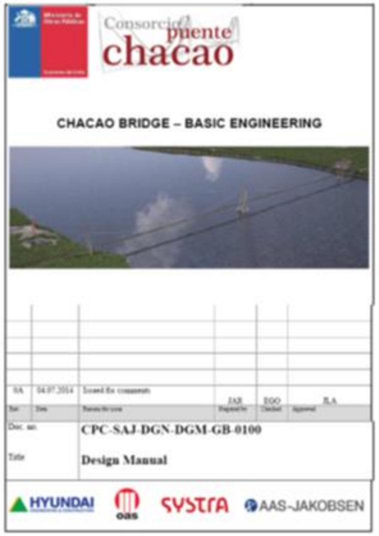
Design Basis

1. Contract (ITB)
2. AASHTO 2012
3. Manual de Carreteras (Chilean code)
4. Other codes where necessary

=> Design Manual





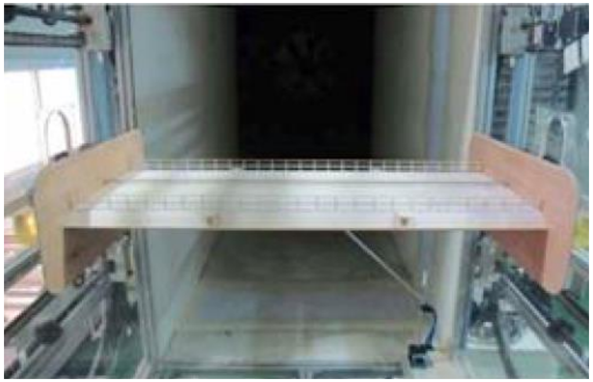
- **Design challenges**

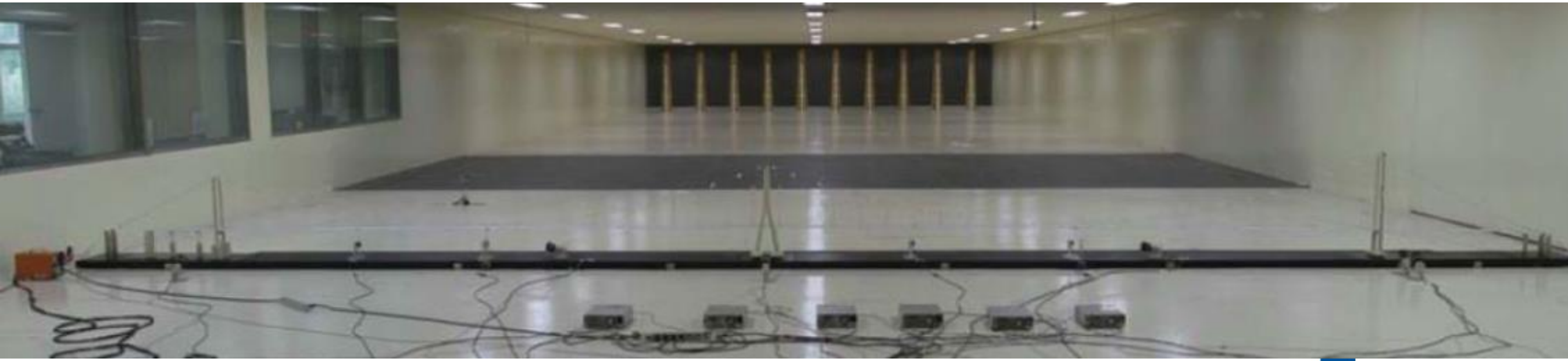
- Project specific requirements unclear
- AASHTO deficiencies
- Manual de Carreteras limitations
- Eurocode
- Japanese code
- Common practice
- Robustness
- Collapse philosophy

Basic engineering

- Soil investigations
- Topography measurements
- Bathymetry measurements
- Wind measurements
- Seimic accelerometers
- Current measurements
- Wave measurements
- Ship traffic survey
- Risk analyses
- Seismic hazard analyses
- Wind tunnel testing

Chacao Bridge – basic engineering





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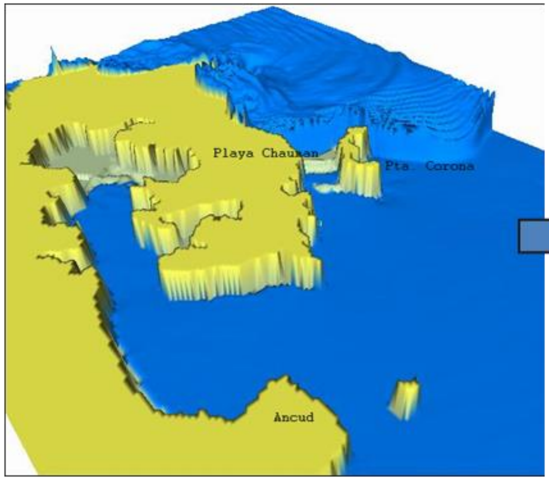
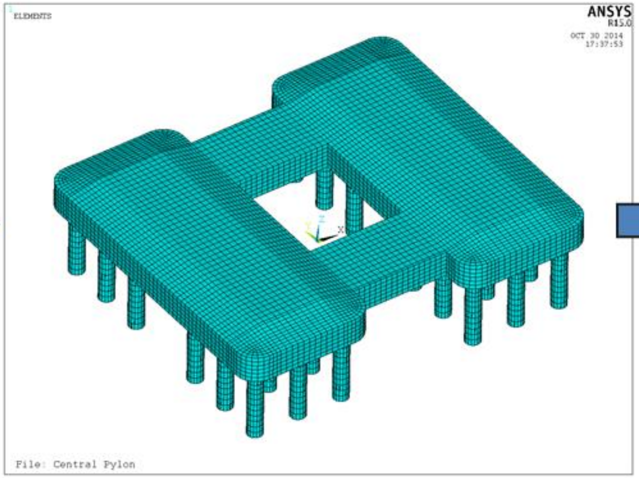
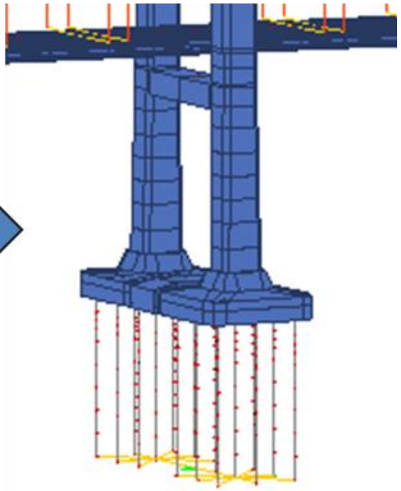
Tsunami

- Hydrodynamic simulations gives a set of Tsunami parameters at the bridge site. (max. wave height, maximum current speed, wave period)
- These values are input to a local marine analysis model (solid elements) which again results in a set of marine loads to be applied in the global model (RM Bridge)







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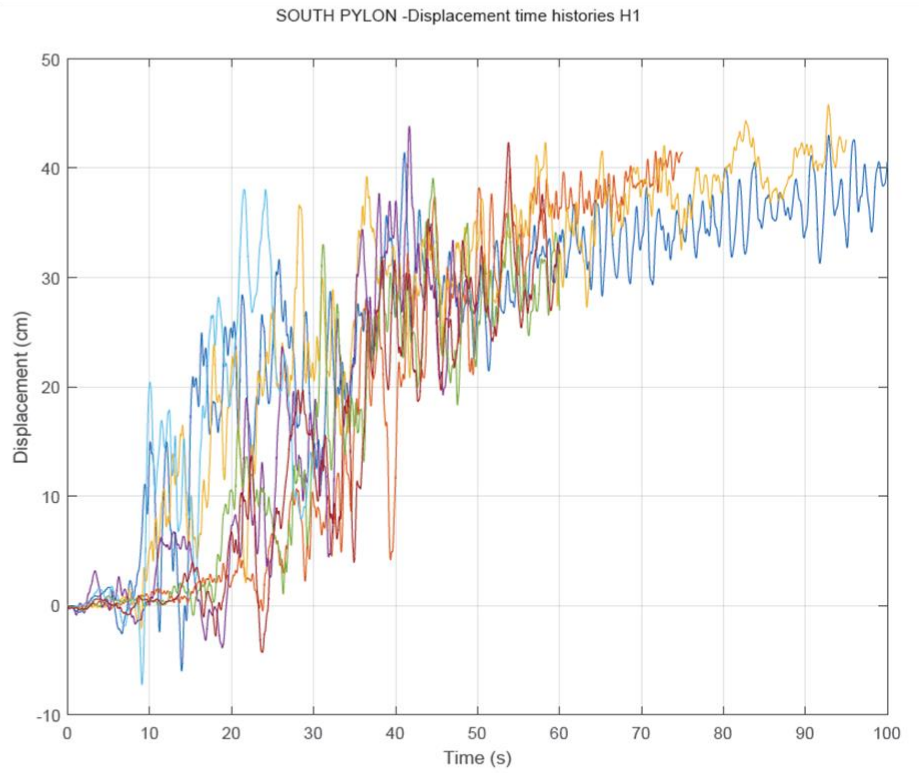
• Seismic analyses

- Seismic hazard analyses
- Time series
- Response spectras
- All directions
- All foundation points
- Different return periods
- Soil structure interaction/ impedance matrices
- Pseudo-static calculations

=>Input Global structural analyses

=>Slope stability during seismic events

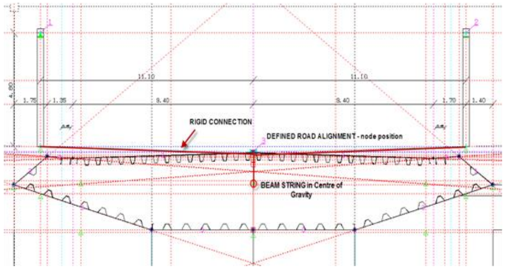
Time history analysis - Earthquake

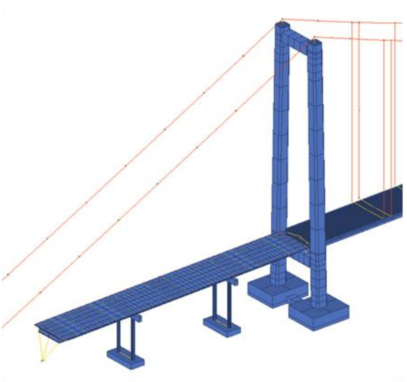


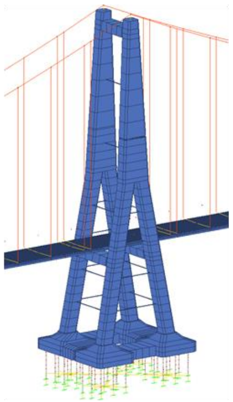
Chacao Bridge – Design

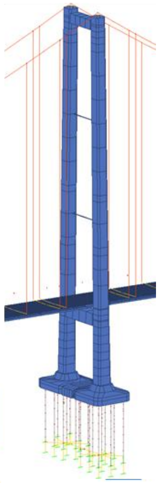
Global model

- RM-Bridge V.10
- 2640 elements
- 9810 degrees of freedom









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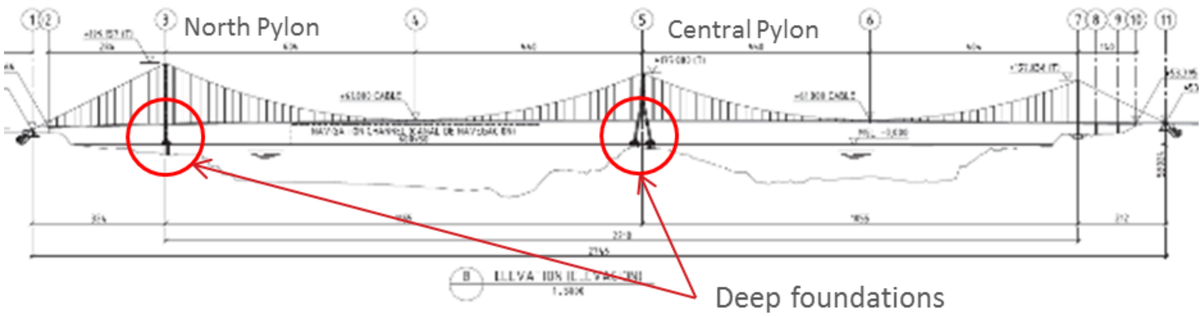
Features

- Large deformations
- Traffic analysis if all adequate traffic loading
- Composite sections
- All applicable static loading
- Dynamic wind analyses
- Dynamic seismic analyses in frequence domain
- Time series analyses
- Push-over analyses

Earthquake Analyses

- Response spectra analyses as basis for design
- Time history analyses to verify results
- Time history analyses to check effects not easily and consistently modelled by the response spectrum method
- Push over analysis to investigate deformation capacity and establish where hinges will occur under an Earthquake exceeding the design earthquake

Chacao Bridge – Design

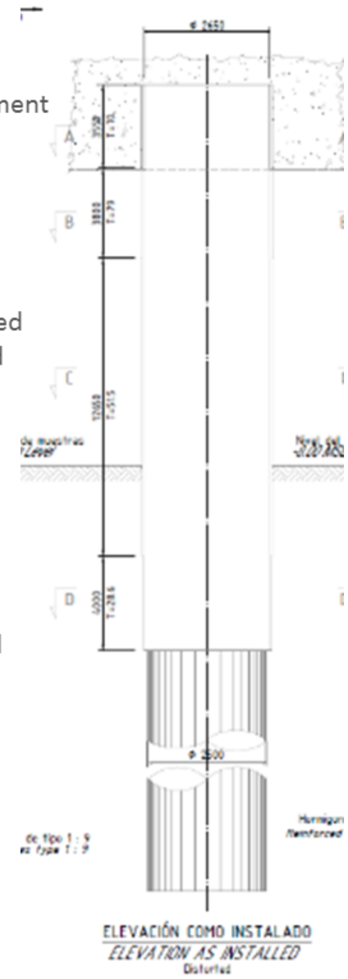


Casing embedment in the pilecap

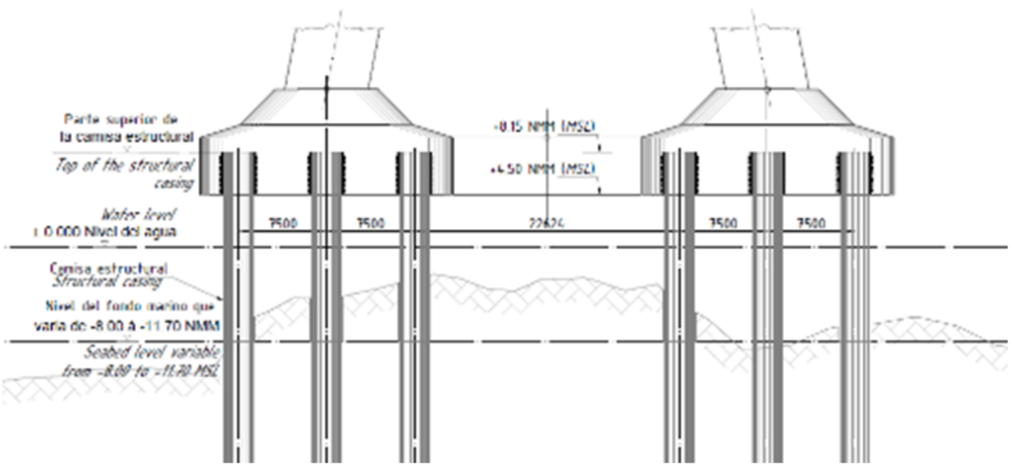
Steel casing filled with reinforced concrete

Bottom of steel casing

Reinforced concrete pile



2.50m Piles diameter with Structural Steel casing up to 79mm thickness



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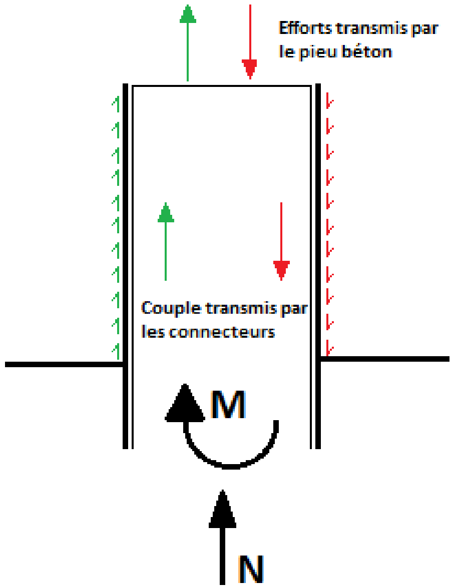
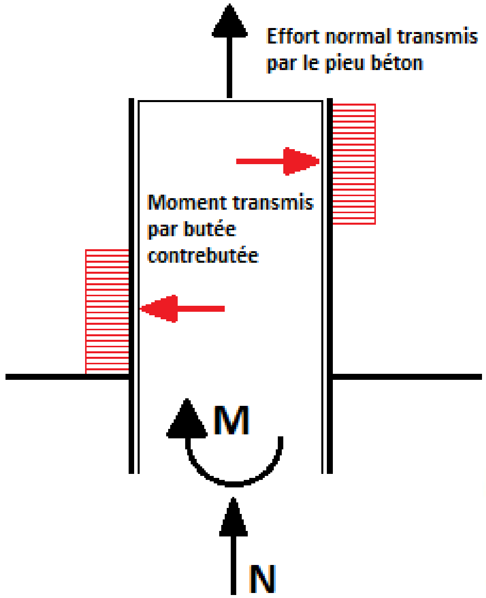
Two distinct mechanisms:

Transfer of the moment in the casing through the shear connectors	Transfer of the moment in the pile through Pressure/contra-Pressure mechanism





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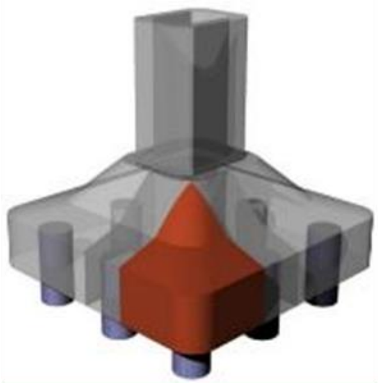
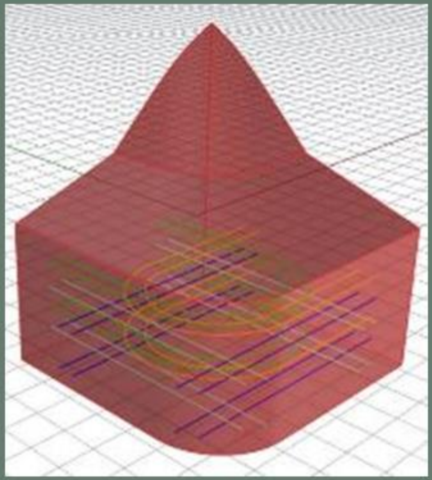
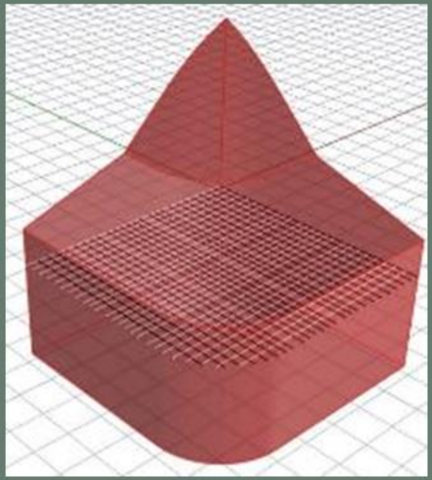
Chacao Bridge – Design

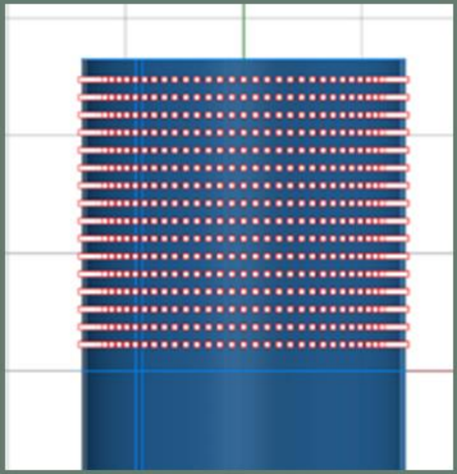


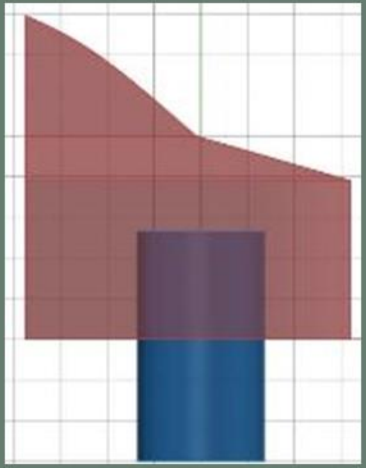
3D Non-linear Model
3rd order Analysis with Code Aster
1/9th of the pilecap

Non-linear materials:
- **Concrete**
- **Structural steel**
- **Prestressing steel**
- **Reinforcing steel**



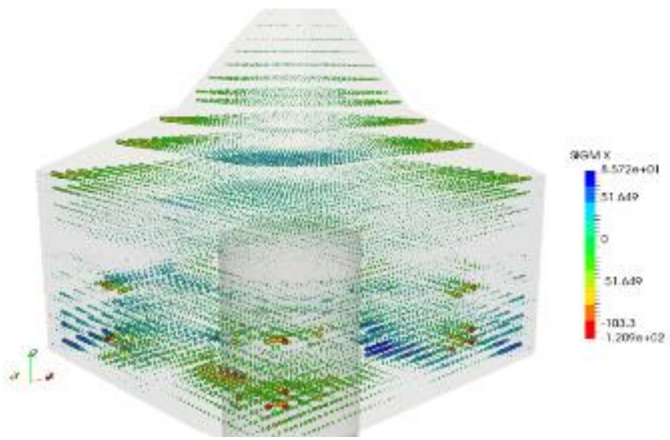




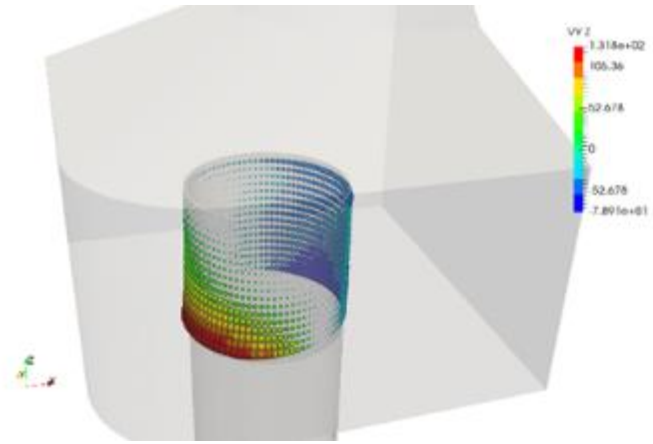


Chacao Bridge – Design

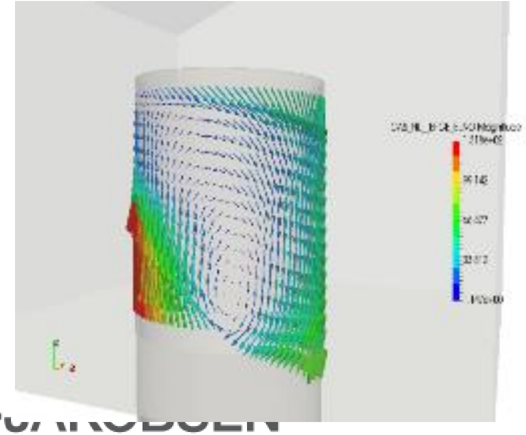
➔ **Stresses in reinforcement**



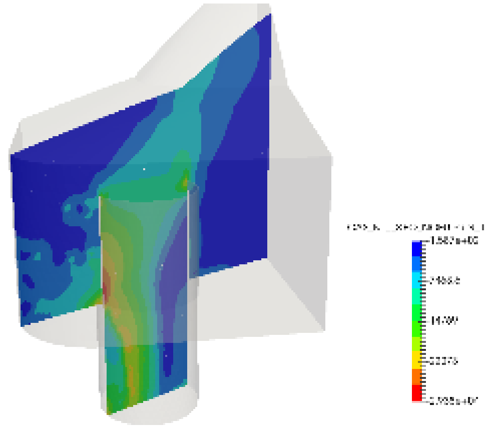
➔ **Forces in shear studs**



➔ **Stresses in steel casing**



➔ **Stress flow in concrete**



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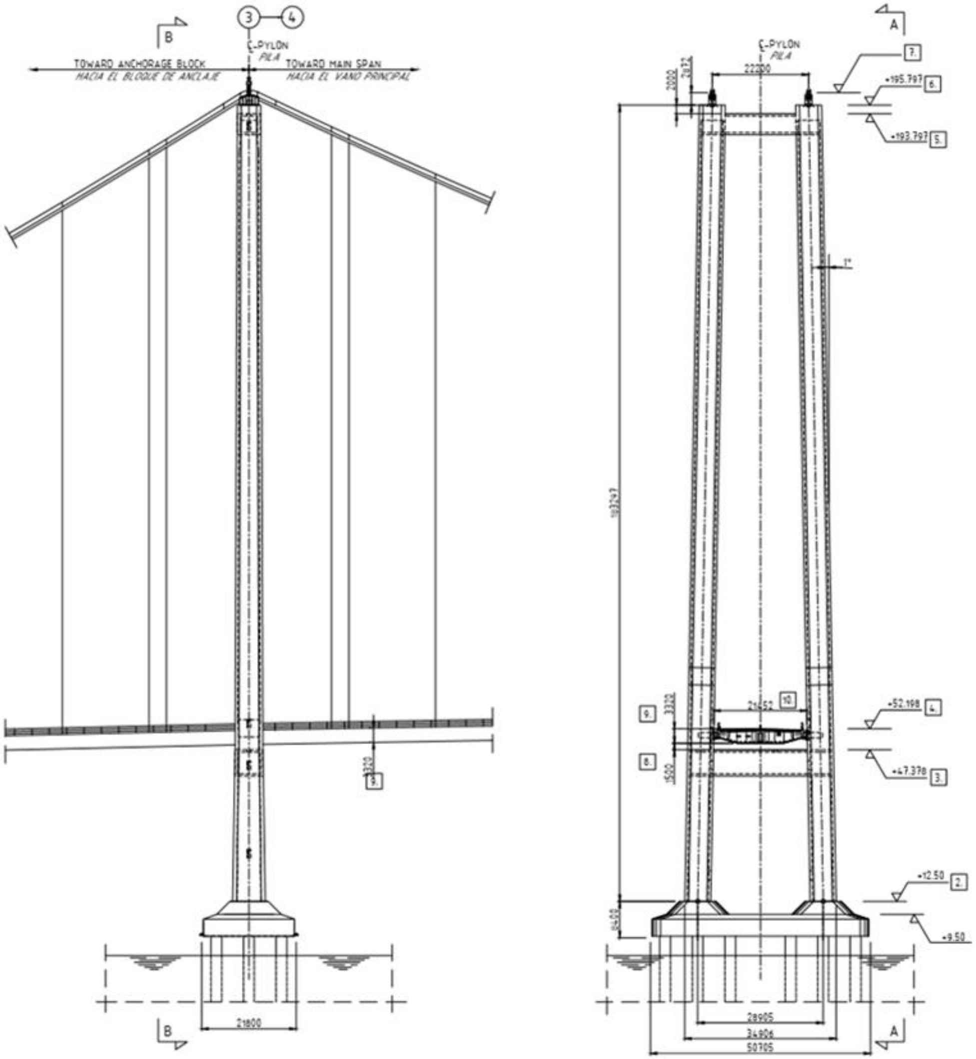

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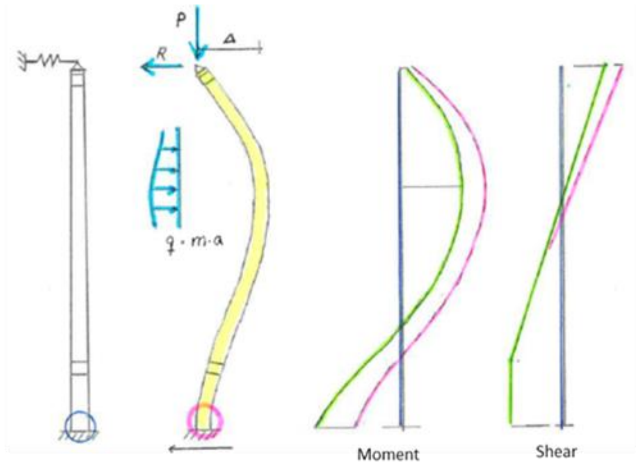
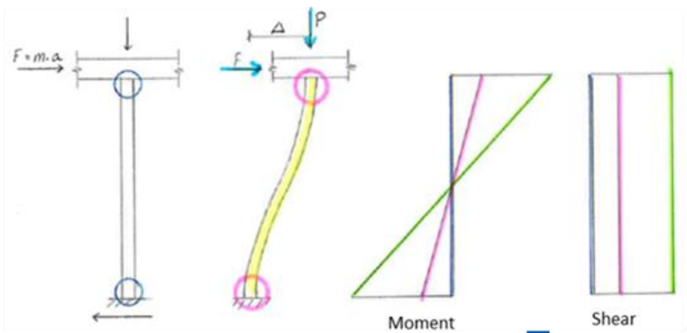
Chacao Bridge – Design

Is it relevant to apply the same Code Requirements to Pylon A as Pier B?

Pylon A



Pier B



Pier B
- Shear Force and Moment is interrelated
- Strength of Hinges and Ductility is interrelated
- Behave inelastically without significant strength loss

Plastic hinge methodolody vs. elastic design approach.

Chacao Bridge – Design

Summary, north and south pylon:

- Heavily reinforced
- Wind on freestanding tower in general governing for design
- Elastic behavior for MPE (1000 year seismic event) and 1.4 x MPE
- BFF 1.4 taken into account to ensure ductile behaviour
- Permanent deflection in seismic events taken into account in the design

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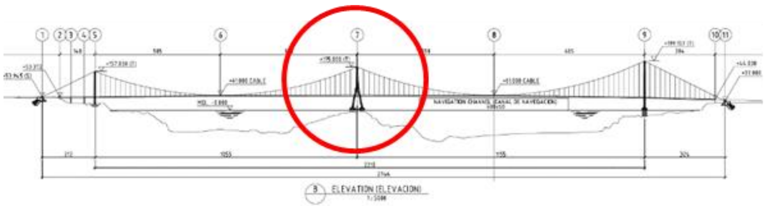

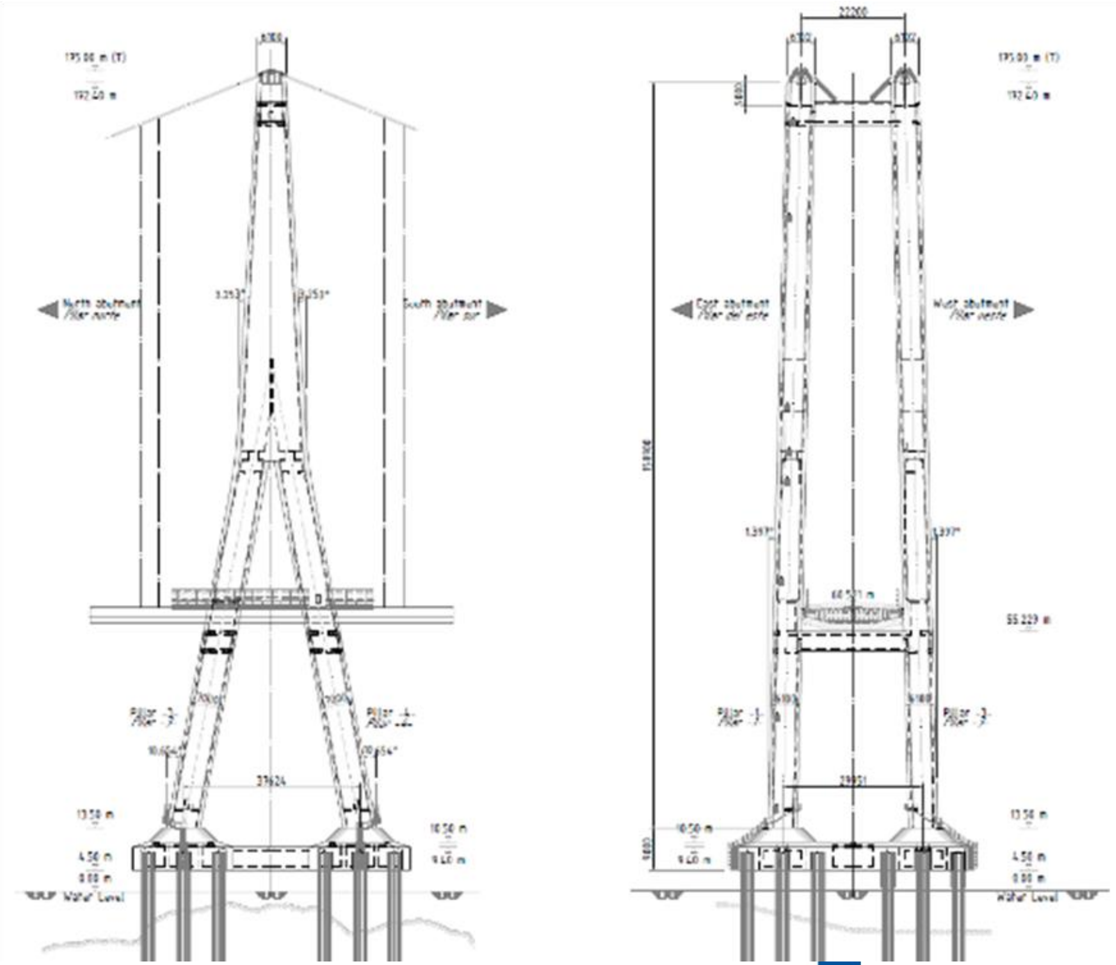

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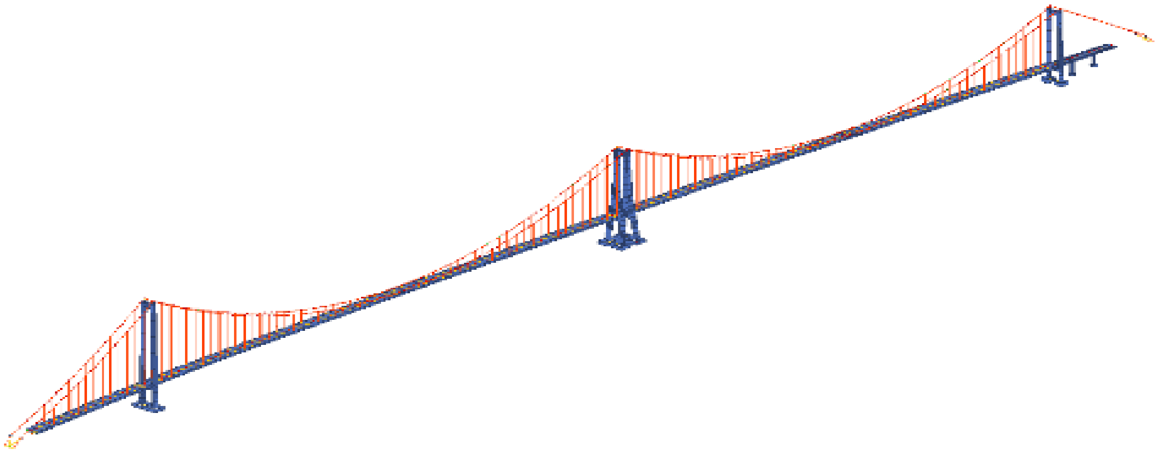
Chacao Bridge – Design

CHALLENGE OF SUSPENSION BRIDGES WITH MULTIPLE SPANS

- If one span only is loaded, there is a large longitudinal bending moment in the central pylon and in the loaded span, and large deck deflection

→ So, the central pylon must be stiff enough

- But if the central pylon is too stiff, there is a large difference in main cable forces on both sides of this pylon, so the cable could slide on its saddle



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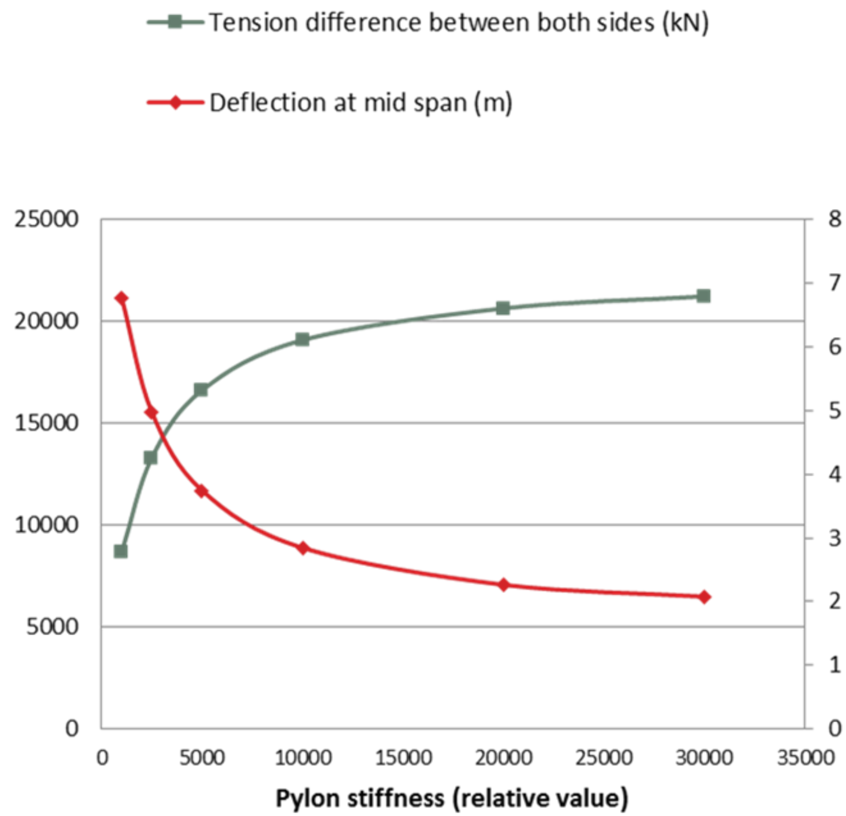
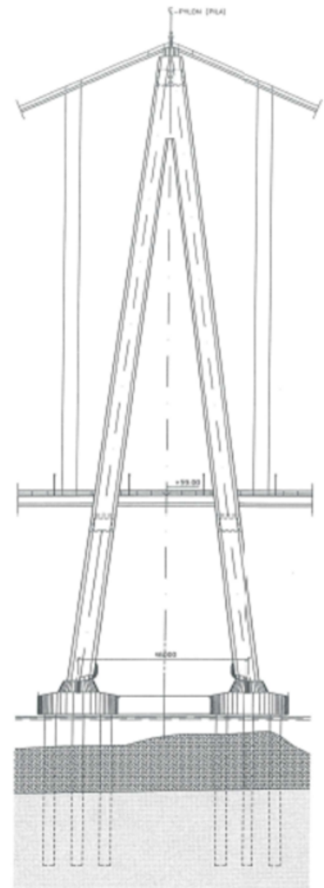
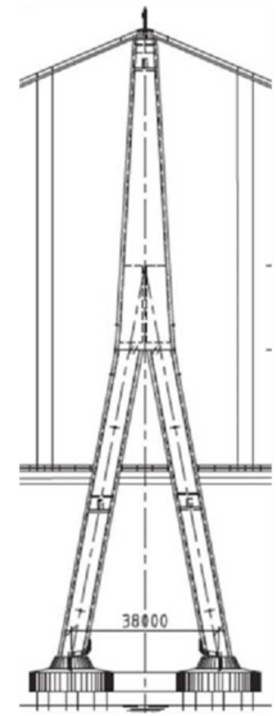


Initial shape



Final shape



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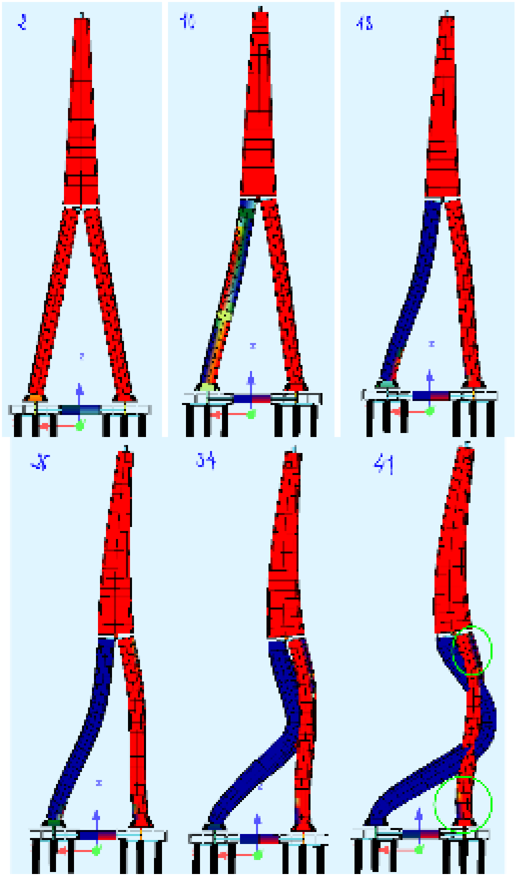
CENTRAL PYLON PUSH-OVER ANALYSIS: PROCESS

- Identify potential 1st plastic hinge.
- Identify 2nd plastic hinge and diffusion of plastic deformation.
- Resize reinforcement for critical locations.
- Check brittle failure
- Check actual strains for each and every step
- Check pylon actual capacity/strains: main client’s concern. What is happening actually for a seismic level higher than the design one (MPE)?



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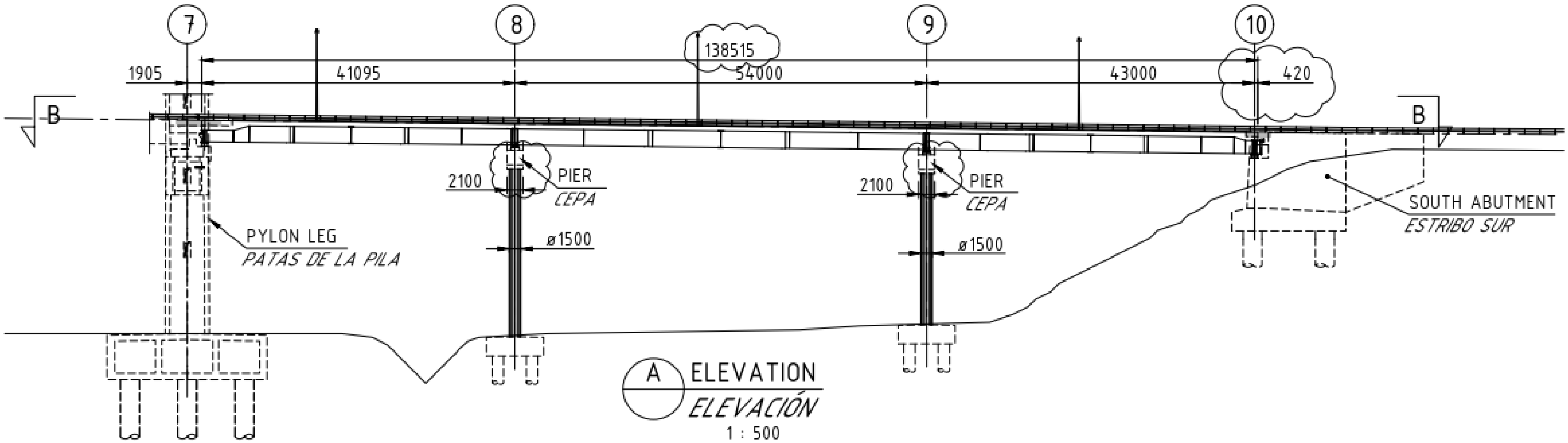

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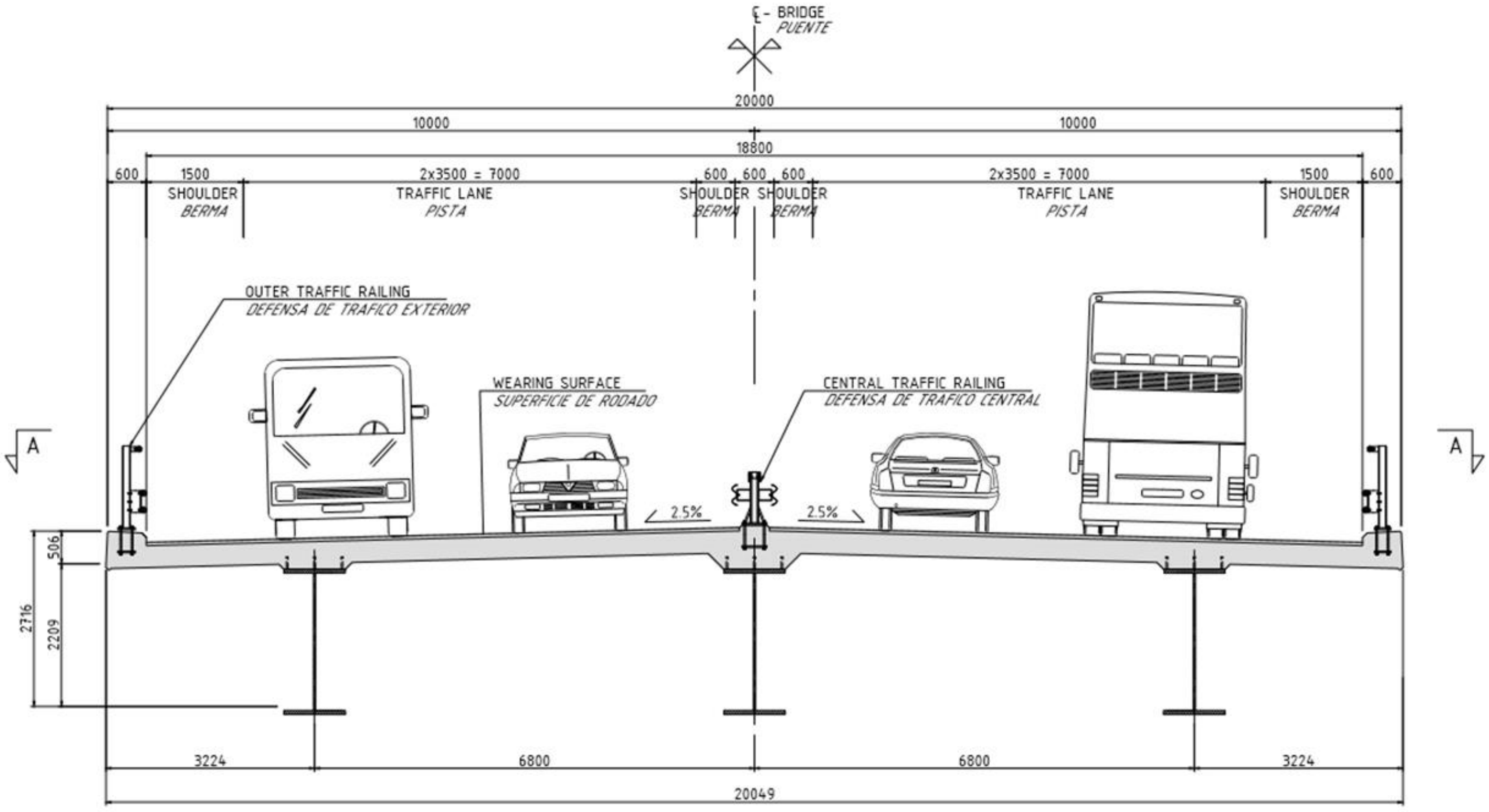

Spans 41m+53m+43m.

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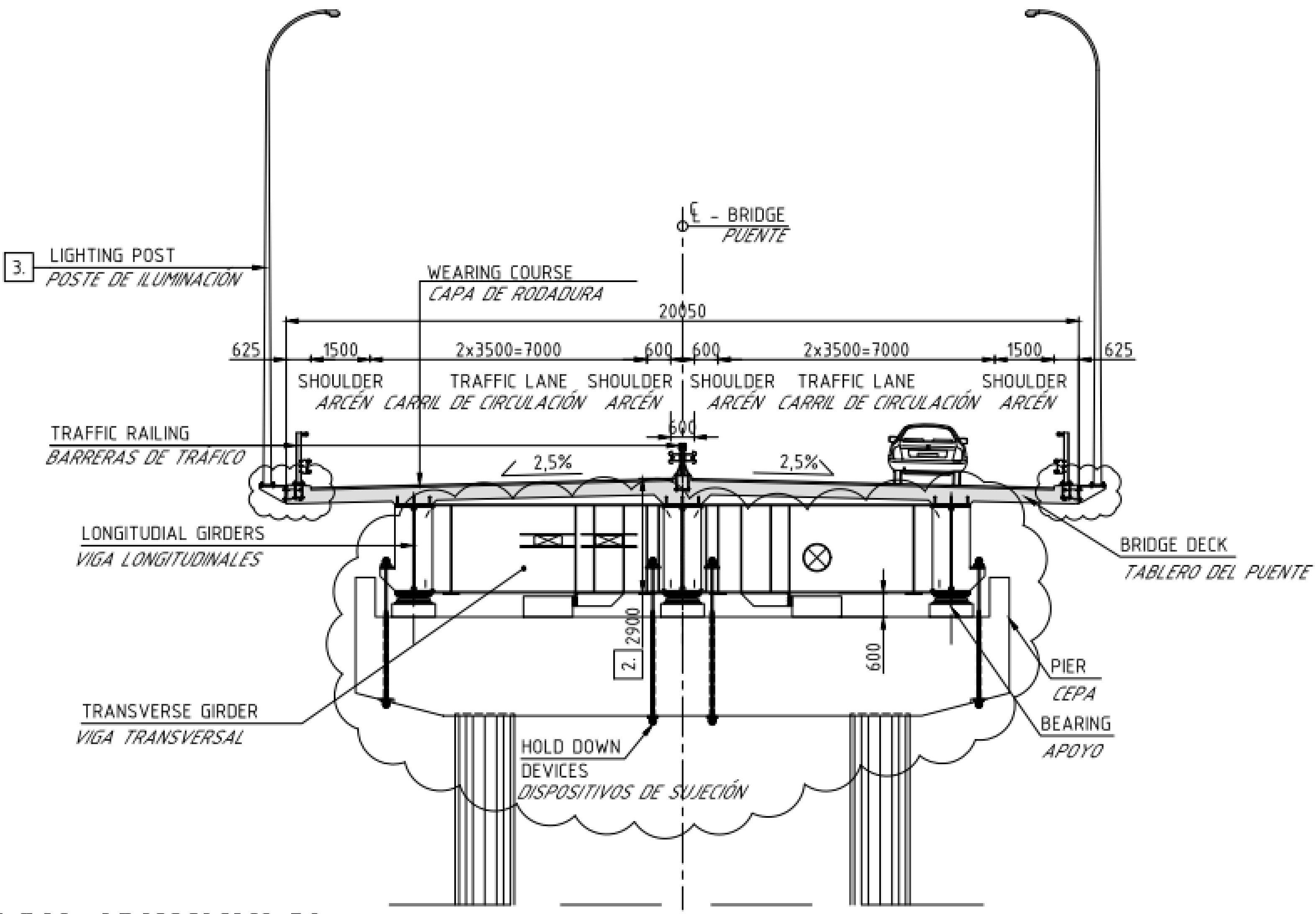

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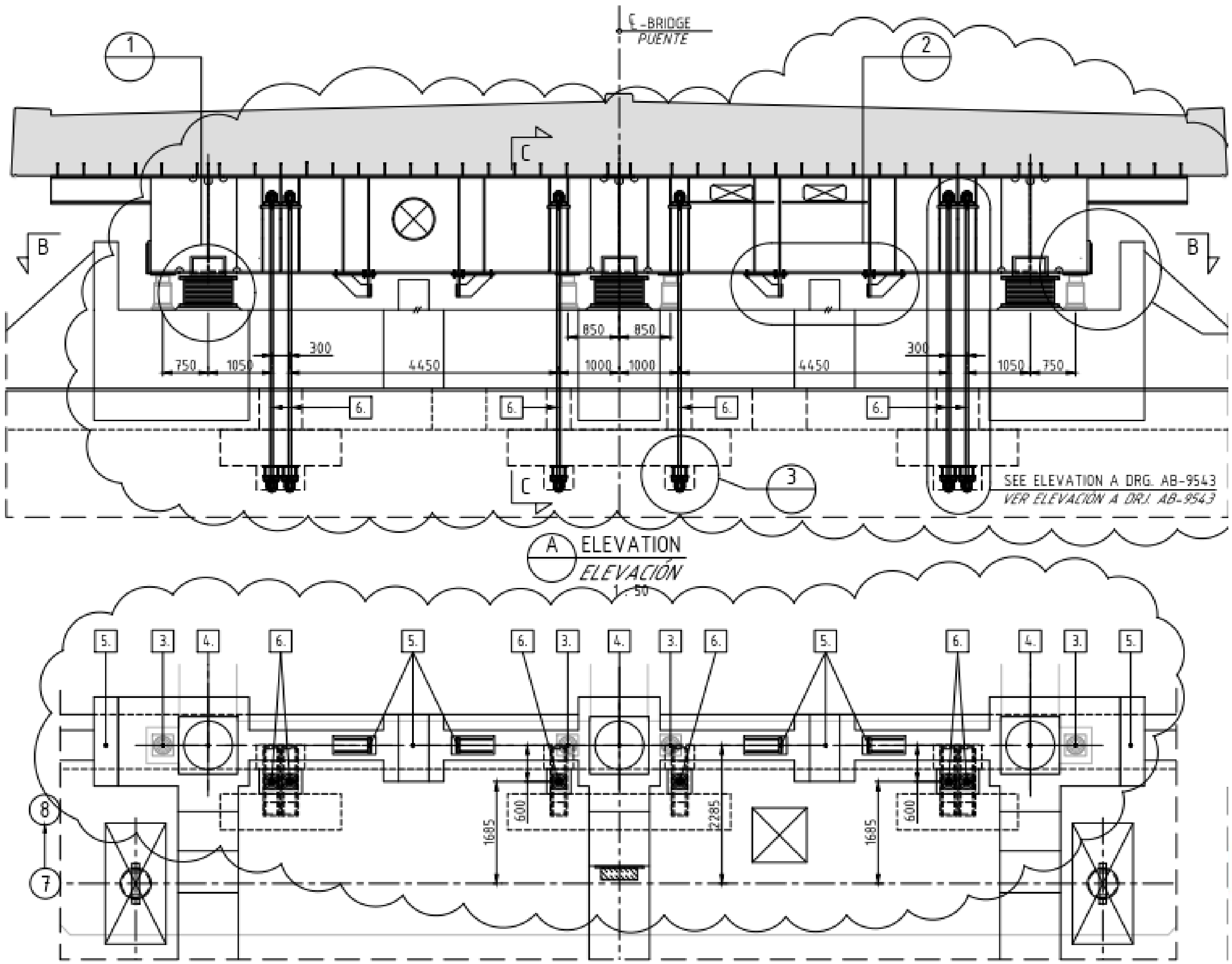

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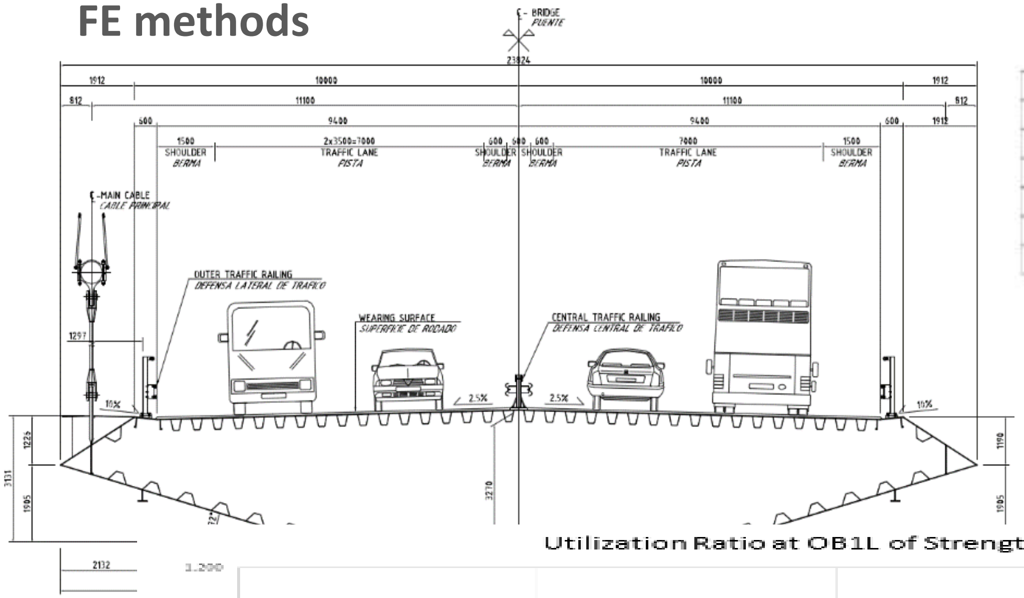
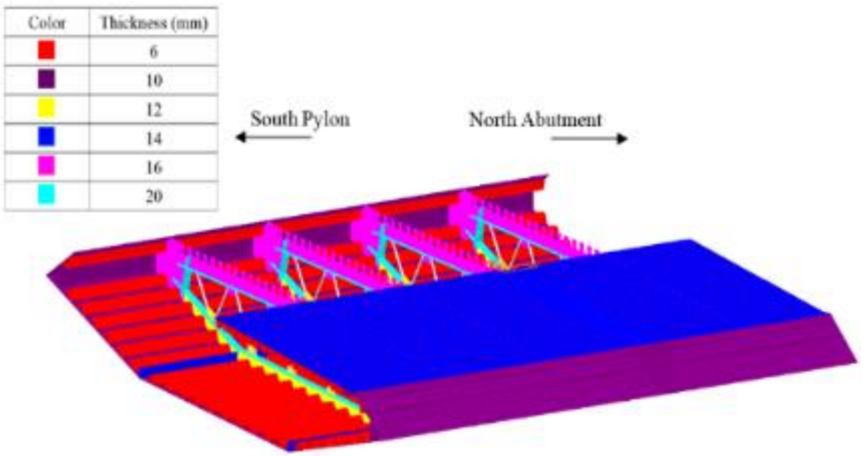
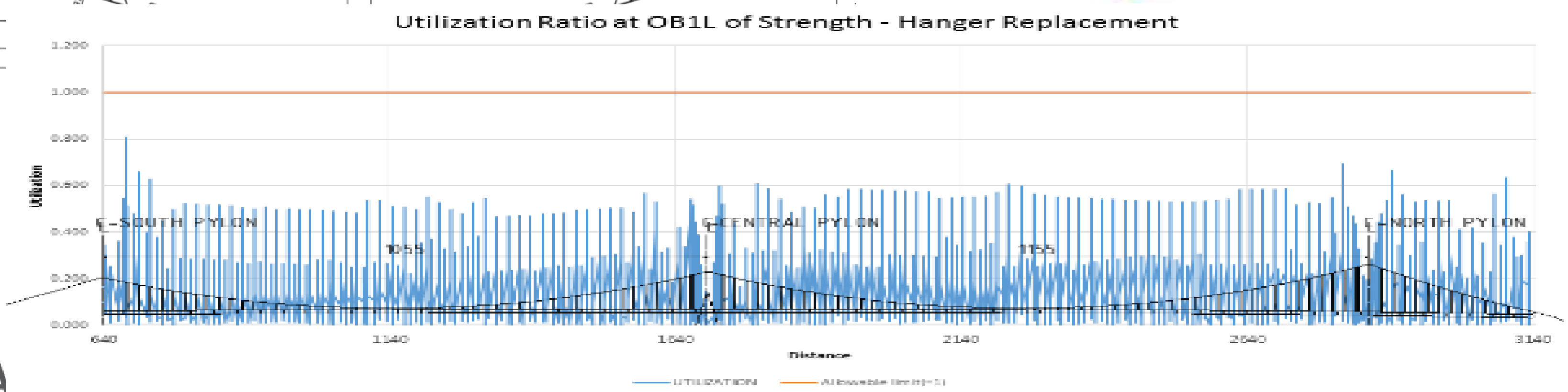
Chacao Bridge – Design

Detailed Design of the Chacao steel box according to AASHTO, using beam or FE methods

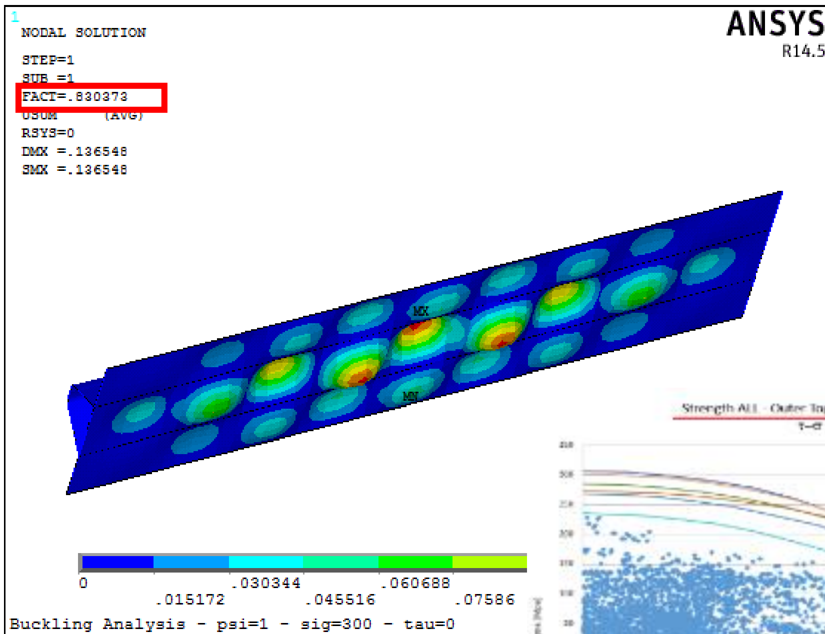


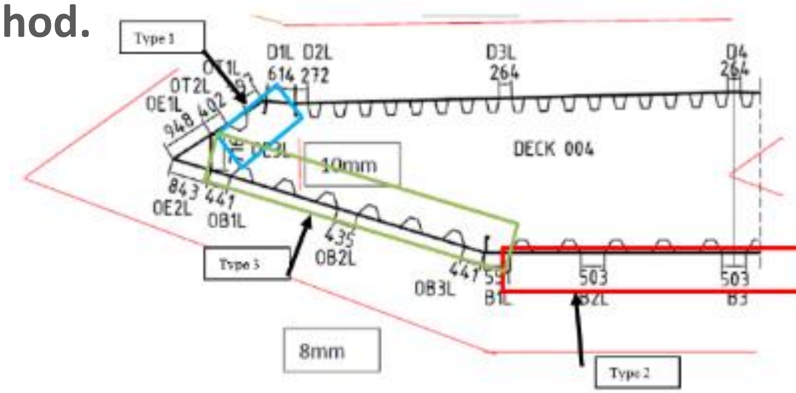


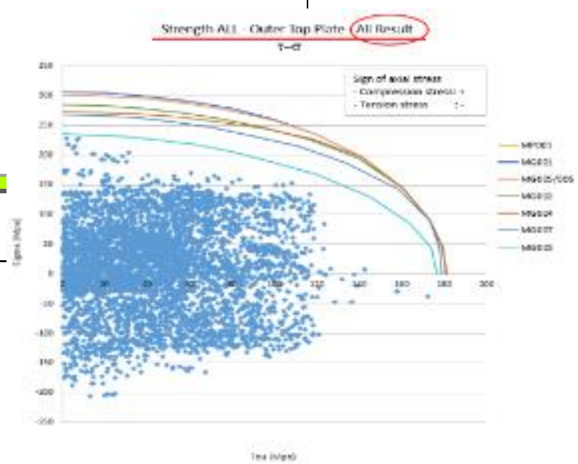


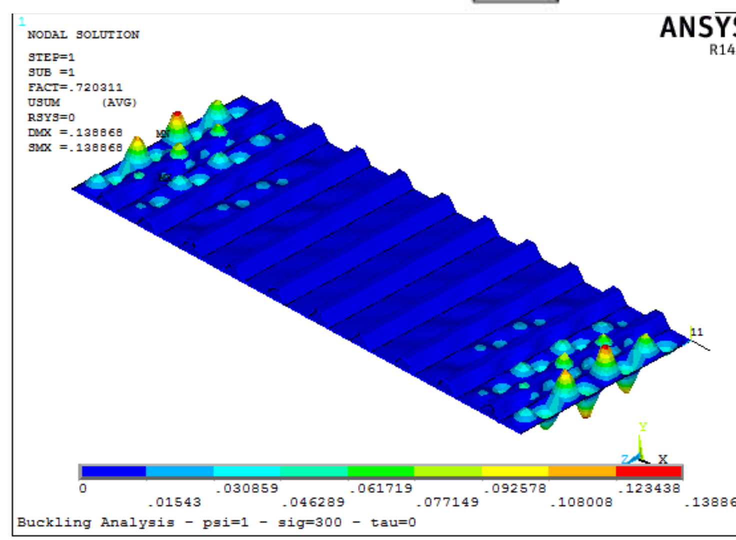
Chacao Bridge – Design

Buckling analysis of a stiffened panel and plot of the resistance interaction curve (s; t), according to the Eurocode FE method.









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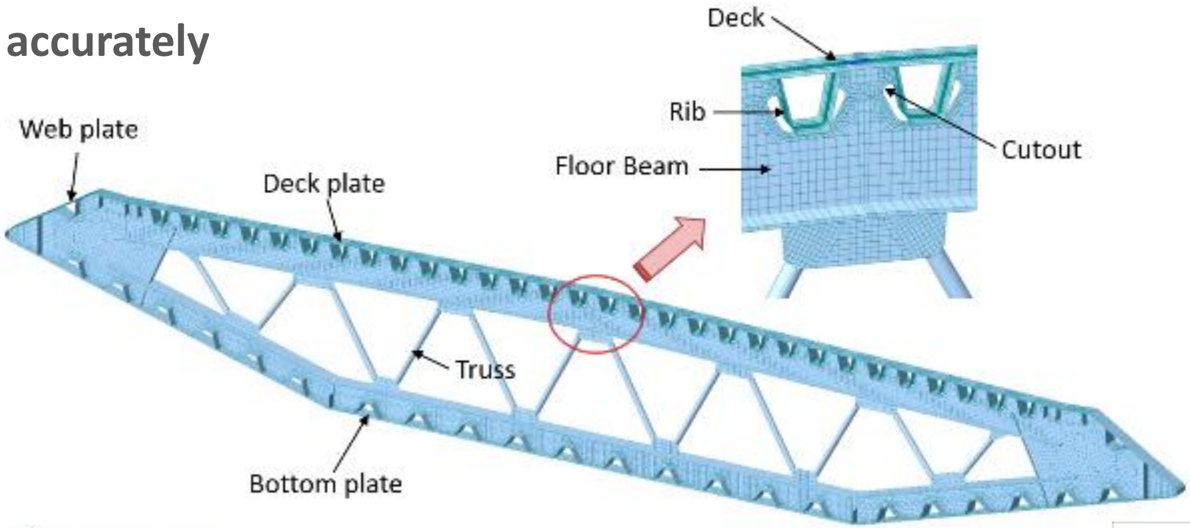
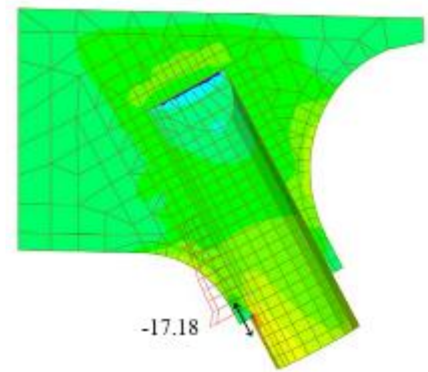
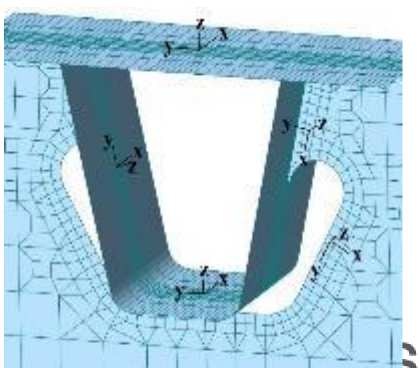
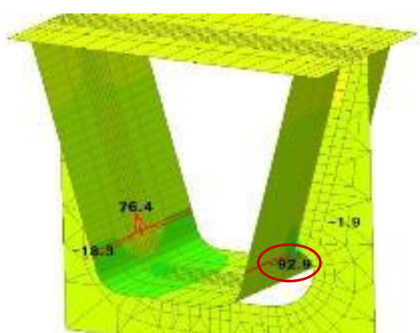
Chacao Bridge – Design

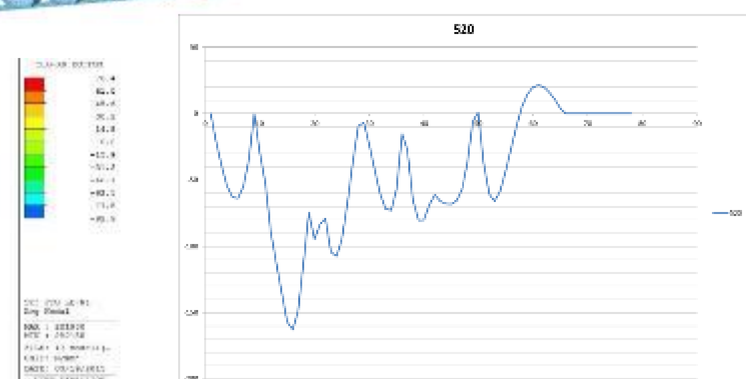
Fatigue analysis of specific details (Orthotropic slab, truss connection …) each detail is studied with a refined model in order to determine the stress range accurately





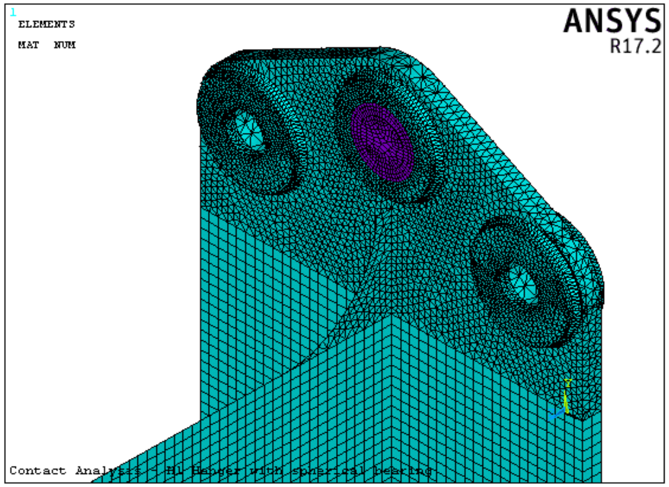


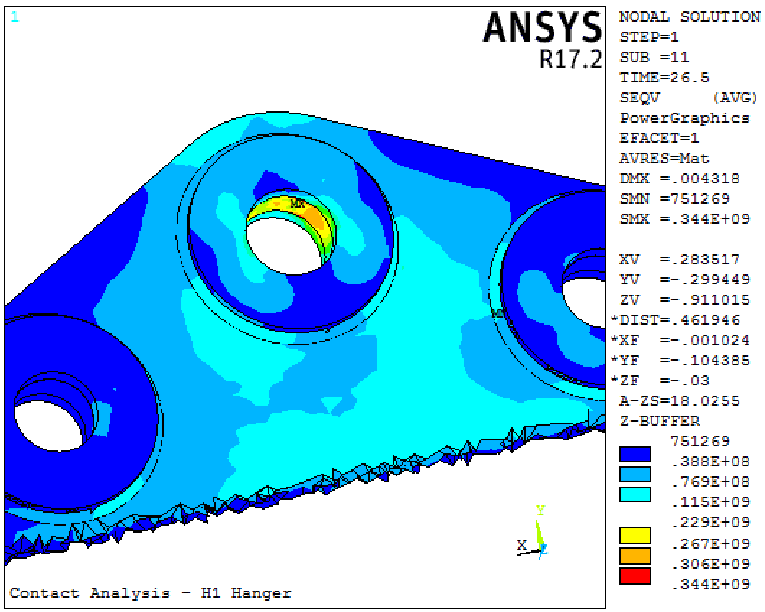


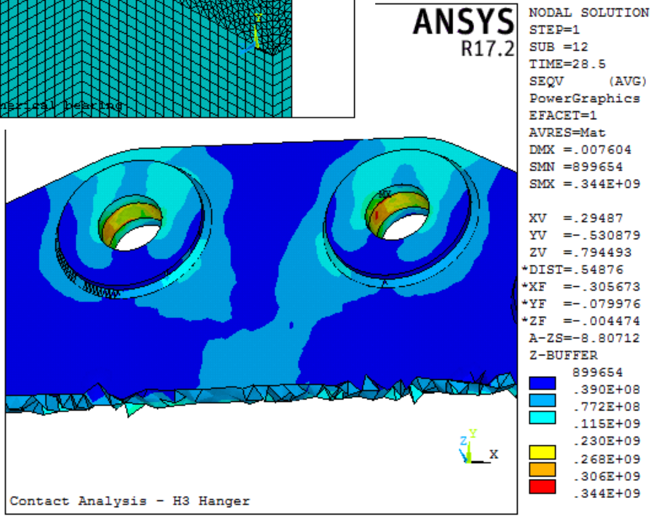


Chacao Bridge – Design

Local design of the hanger anchorage plate
3D Non-Linear FE Analysis with solid elements in ANSYS







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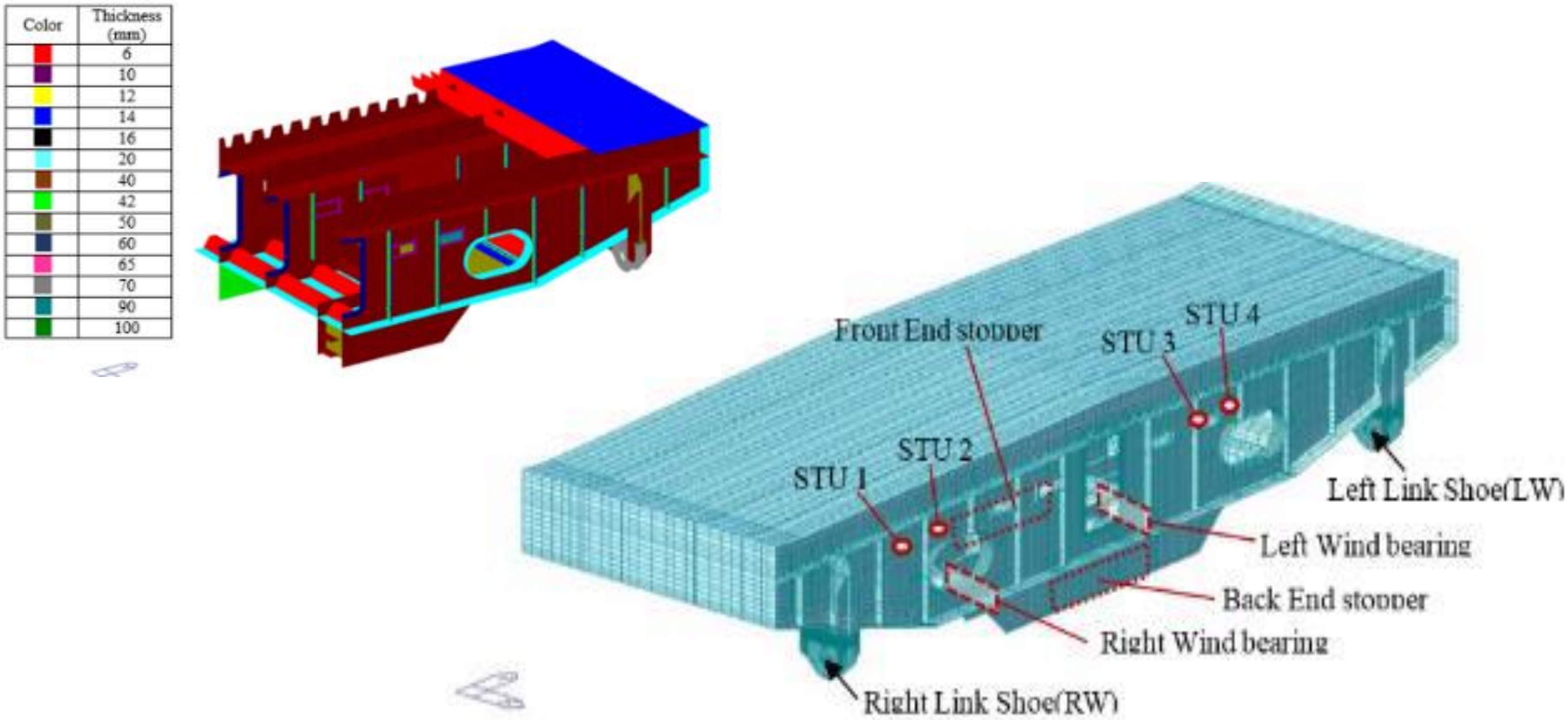
Chacao Bridge – Design

Local FE model at the end of the bridge girder which describes the boundary conditions (Link shoes, buffers, wind bearings …) with MIDAS



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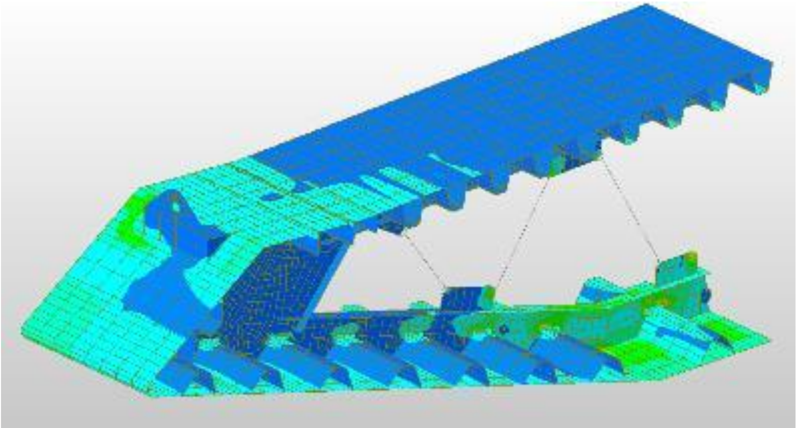
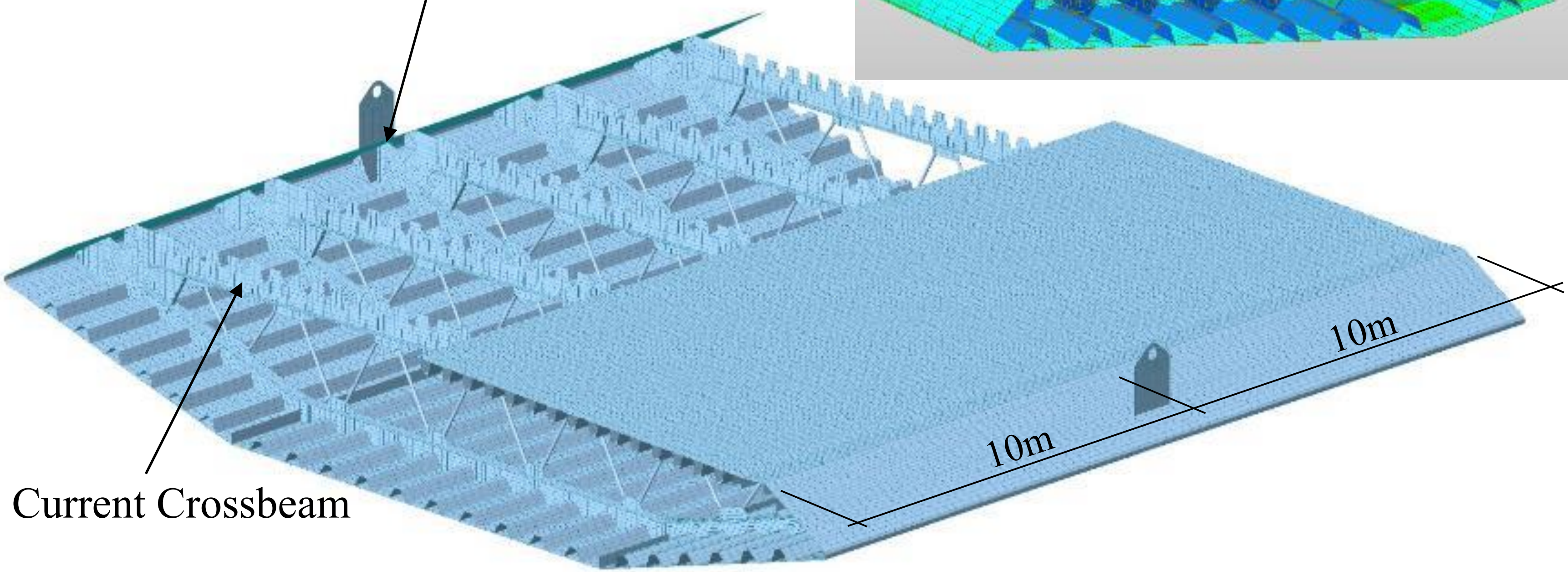
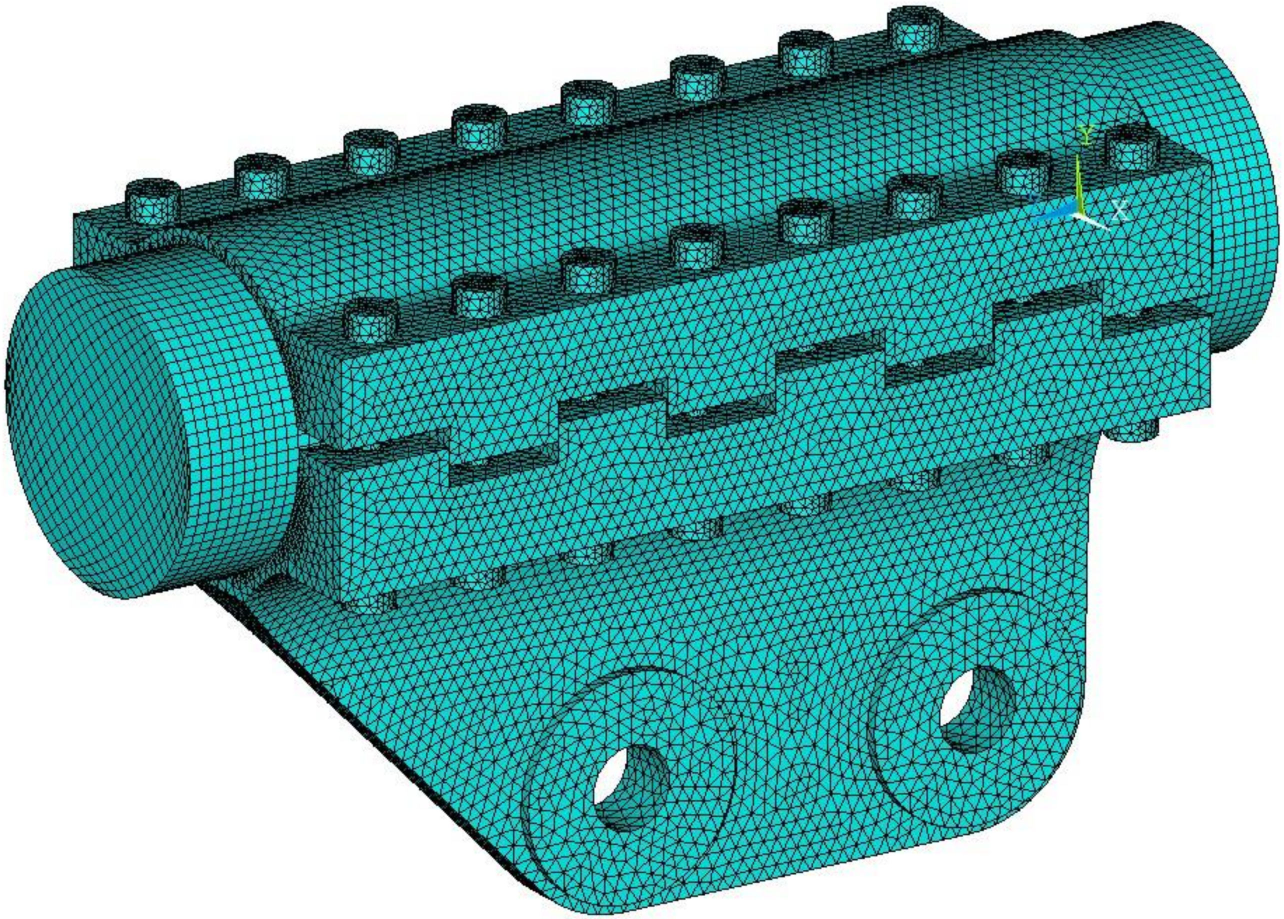
Chacao Bridge – Design

- FEA Models Crossbeams
- Crossbeam spacing : 4m





Chacao Bridge – Design



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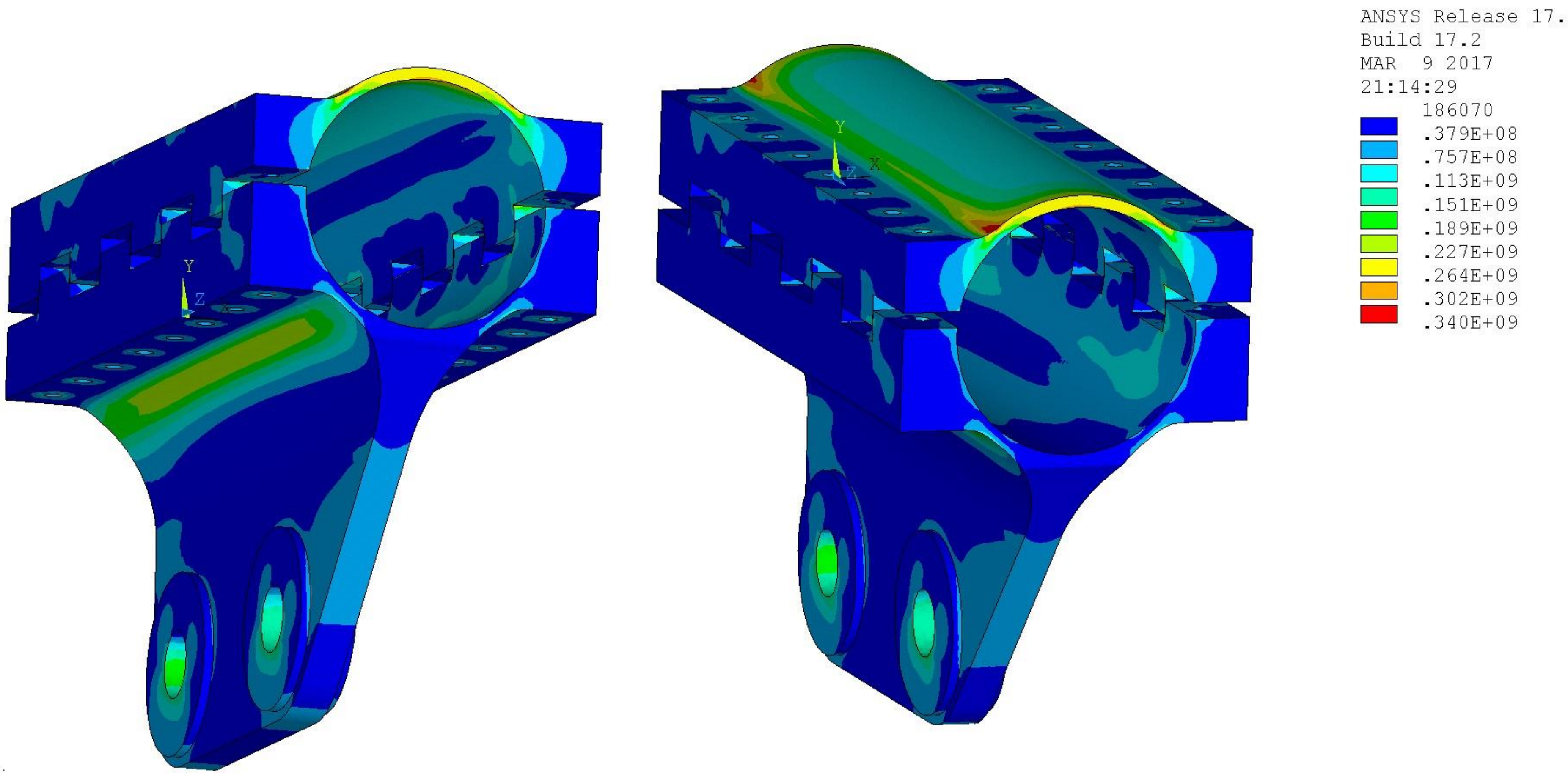
Chacao Bridge – Design



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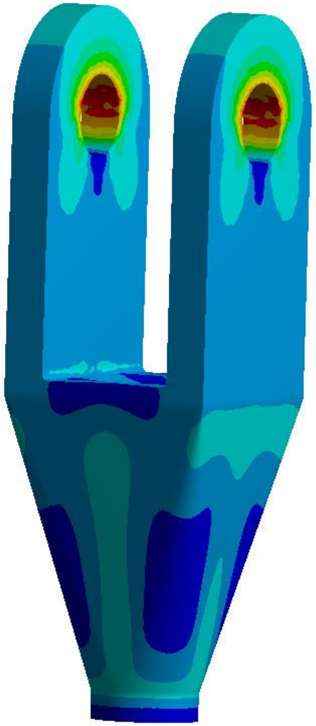
Chacao Bridge – Design



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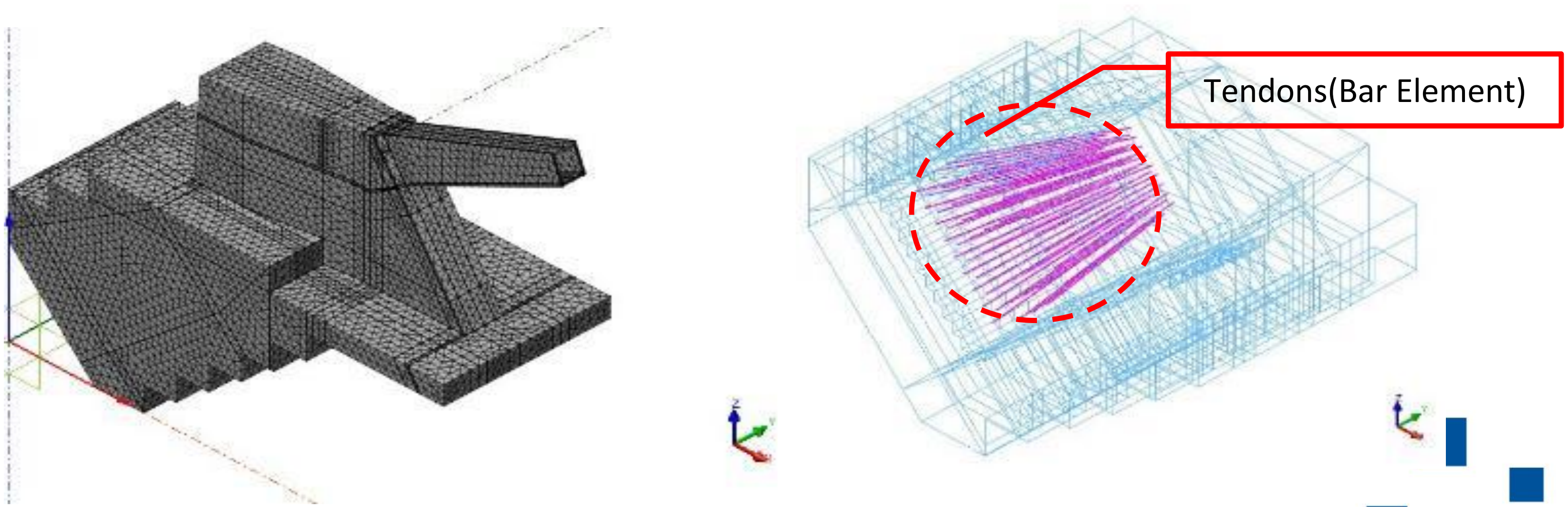
Chacao Bridge – Design

- 3D Finite Element Model for North and South Anchorage Blocks
  - Half model considering symmetric boundary condition
  - Solid Element for concrete and bar element for tendons
  - Consideration of soil stiffness for each layer
  - Consideration of main construction sequences



3D Finite Element Model for North Anchorage Block

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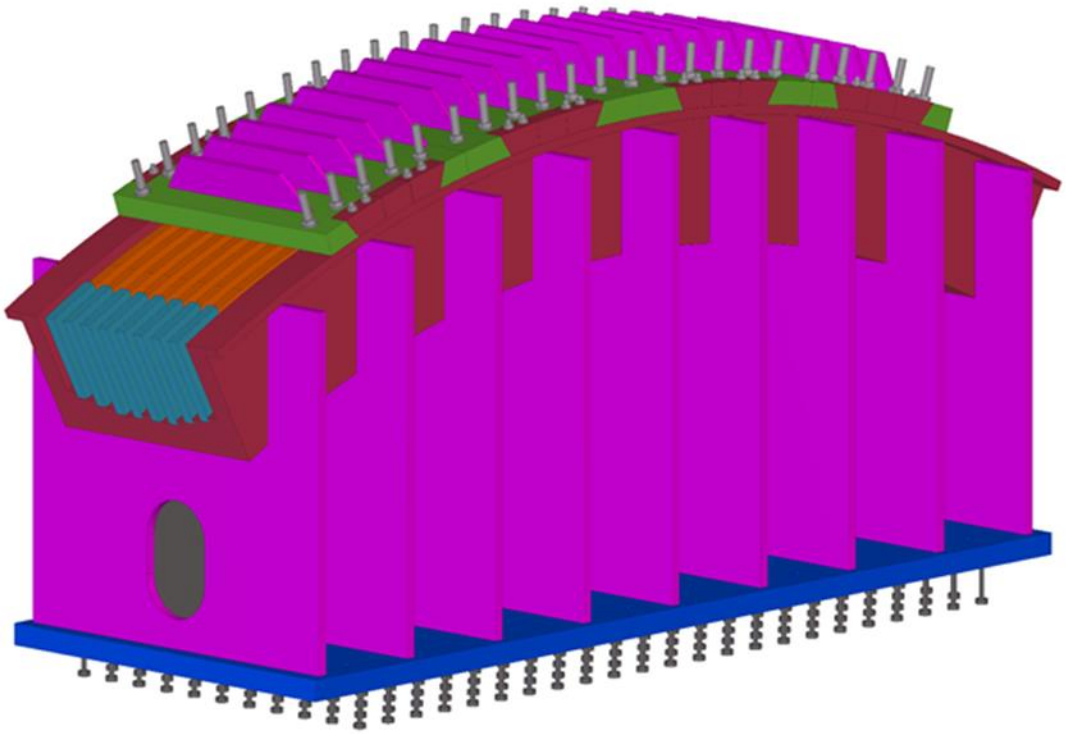
Chacao Bridge – Design



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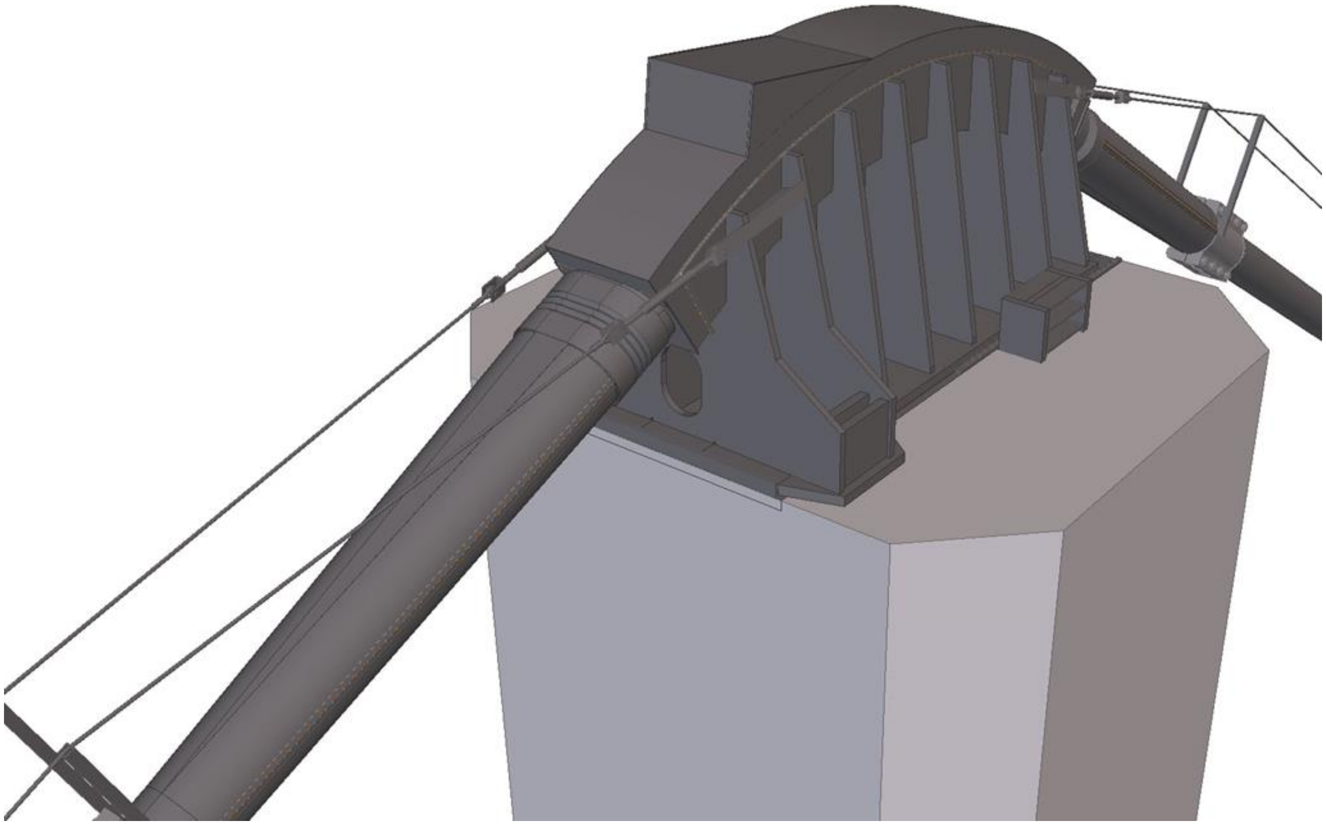
Chacao Bridge – Design



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Chacao Bridge – Design

Outfitting and equipment

- **FMU**
- **Access**
- **Inspection wagons**
- **Roadway outfitting**
- **SHMS**
- **Dehumidification systems**

Chacao Bridge – Design

01 de Marzo de 2018

Comienza construcción definitiva del Puente Chacao en el sur de Chile

La obra será ejecutada en 60 meses con un presupuesto superior a US$700 millones

Enviar a un colega   Mensaje al editor   Imprimir

Compartir en redes sociales

A bordo de un transbordador que recorrió la zona de faenas que realiza la plataforma Jack Up Pionner III en el Canal de Chacao, Región de Los Lagos, el ministro de Obras Públicas anunció la construcción definitiva del puente que conectará a la isla de Chiloé con el continente. Durante el recorrido, el equipo técnico de la empresa coreana Hyundai, a cargo de la construcción del puente, recibió los planos de construcción.

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Chacao Bridge – construction

29. June 2018 – Site visit president Piñera

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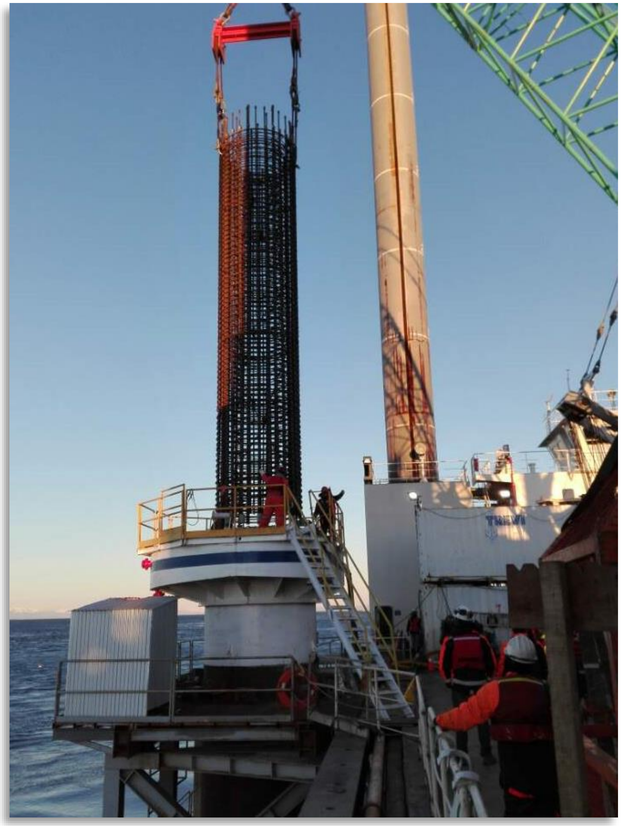
Chacao Bridge – construction

Pile installation Central Pylon



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Chacao Bridge – Lessons learned

- Technical challenges due to site conditions solved
- Technical challenges due to seismic demands solved
- Complete designs delivered several times, final issue July 2018
- Construction ongoing

Chacao Bridge – Lessons learned

Risk planning and risk management is increasingly important, here:

- Client
- Business culture
- Local authorities
- Language
- Currency
- Contract
- Tender specifications
- Site conditions
- Environmental data
- Technical challenges

		Consequence				
		Insignificant	Minor	Moderate	Major	Severe
Likelihood	Almost certain	Medium	High	High	Extreme	Extreme
	Likely	Medium	Medium	High	Extreme	Extreme
	Possible	Low	Medium	Medium	High	Extreme
	Unlikely	Low	Low	Medium	High	High
	Rare	Low	Low	Low	Medium	High

However;

The value of this reference and the increased knowhow/experience is **HUGE.**

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Chacao Bridge – construction

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Thank you for your attention

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