ANALYSIS OF STEEL TANKS IN CHILE SUBDUCTION EARTHQUAKES

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GENERAL TOPICS

Non-Building Structures

Observed Failures

Seismic Activity

Seismic Response

Backward Seismic Analysis

Seismic Horizontal Sliding of Self-Anchored Steel Tanks (Proposal)

Final Comments

Main Aspects

Petroleum, Liquid Gas, Sulphuric Acid, Water Storage

Self-Anchored

Anchored

Very important in the seismic response

Continuity of Operation in Industry

Non-interruption of essential processes and services

Prevent or minimize the standstill of operations

Enable the inspection and repair of damaged elements

Observed Tanks Failures on Earthquakes

Earthquake	Mag.	Principal Failures						
		RS	**BS**	WR	CB	RP	AB	**HS**
Chile 1960 (1)	9.5		X		X	X		X
Alaska 1964	9.2		X			X	X	X
Armenia 1972	7.0	X	X		X			
Loma Prieta 1989	6.9	X	X	X				X
Chile 1985 (1)	7.8		X					
Hokkaido 1993	7.6		X					X
Northridge 1994	6.7	X	X		X	X	X	X
Chile 2007 (1)	7.7		X					X
Observed Failures (%)		38	**100**	13	38	38	25	**75**
Chile 2010 (2)	8.8	ND	ND	ND	ND	ND	ND	ND

Rupture of Shell Wall : RS
Buckling Shell (Foot Elephant) : BS
Failures in Joints Wall – Roof : WR
Failures in Columns and Beams : CB
Rupture in Roof Plates : RP
Rupture of Anchorage Bolts : AB
Horizontal Sliding : HS

(1) Self-Anchored. Damage
(2) Anchored. **No Damage**

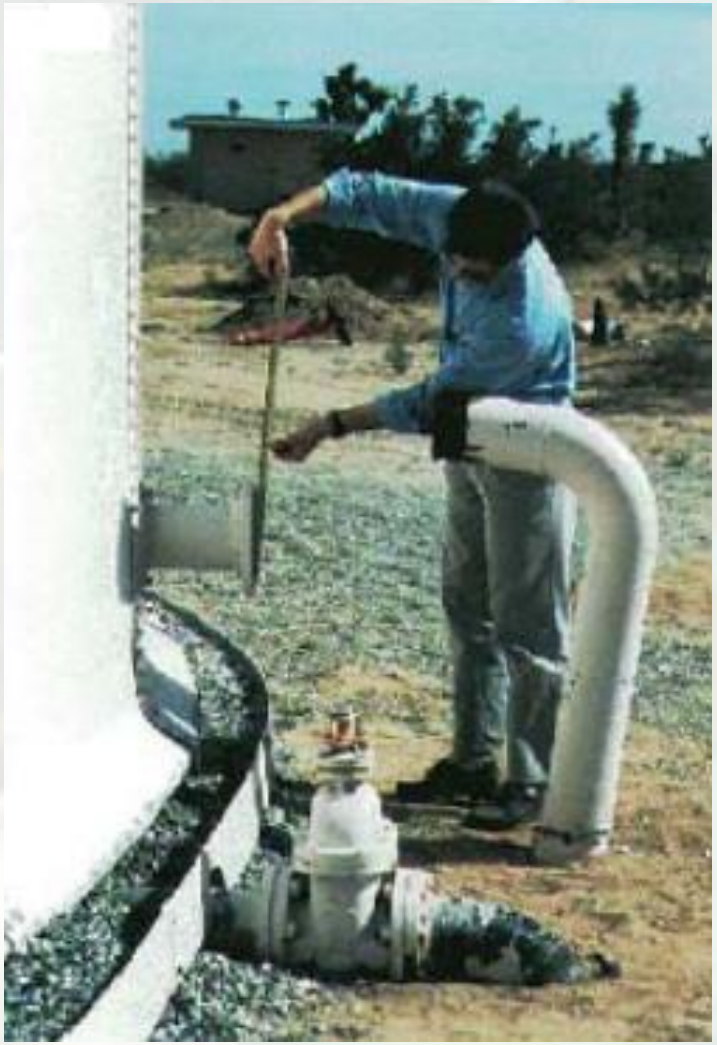
(Pineda & Saragoni (2016))

Design mainly with API Standard 650

Main Fails Observed on Earthquakes

Buckling Shell

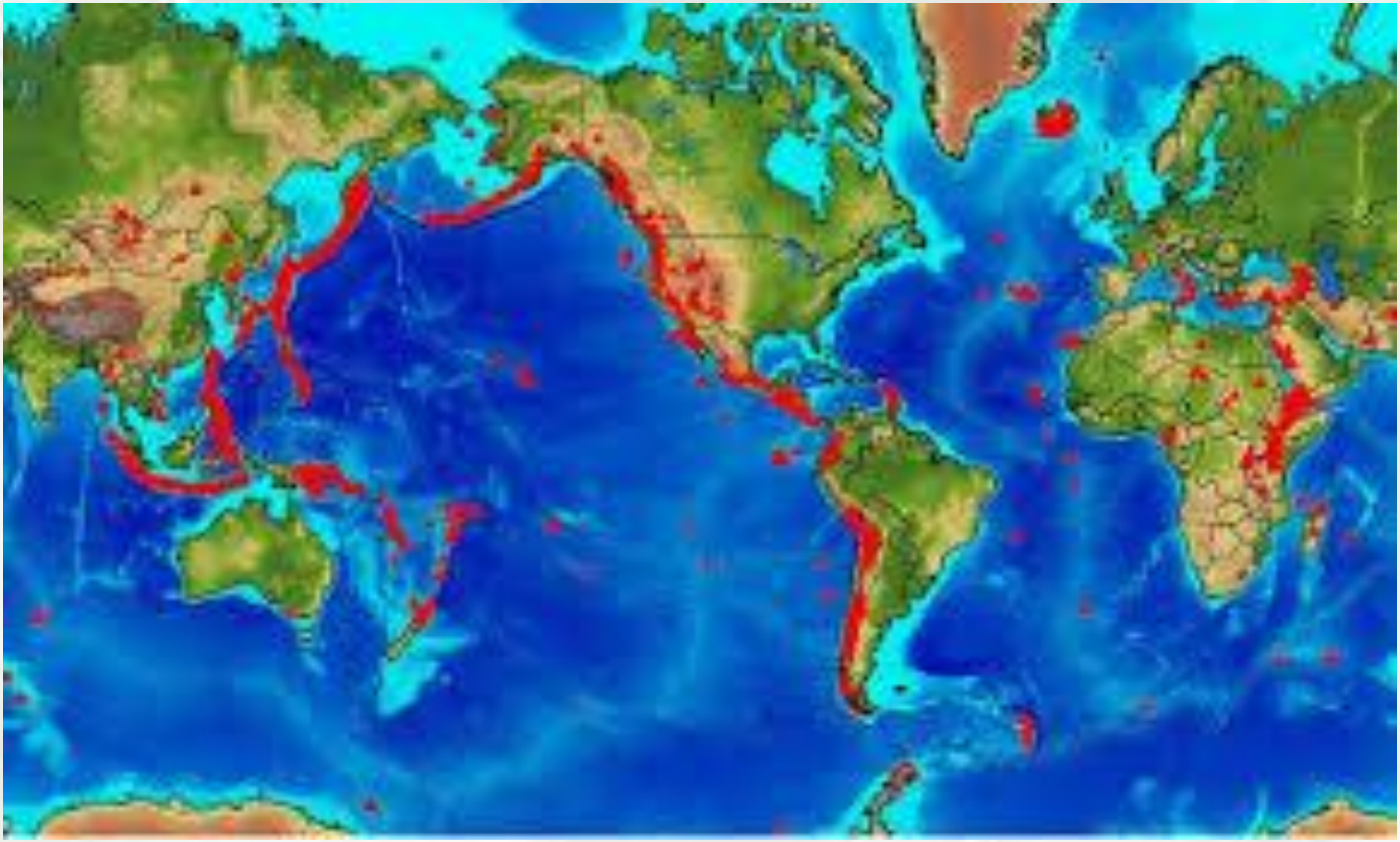
(BS)



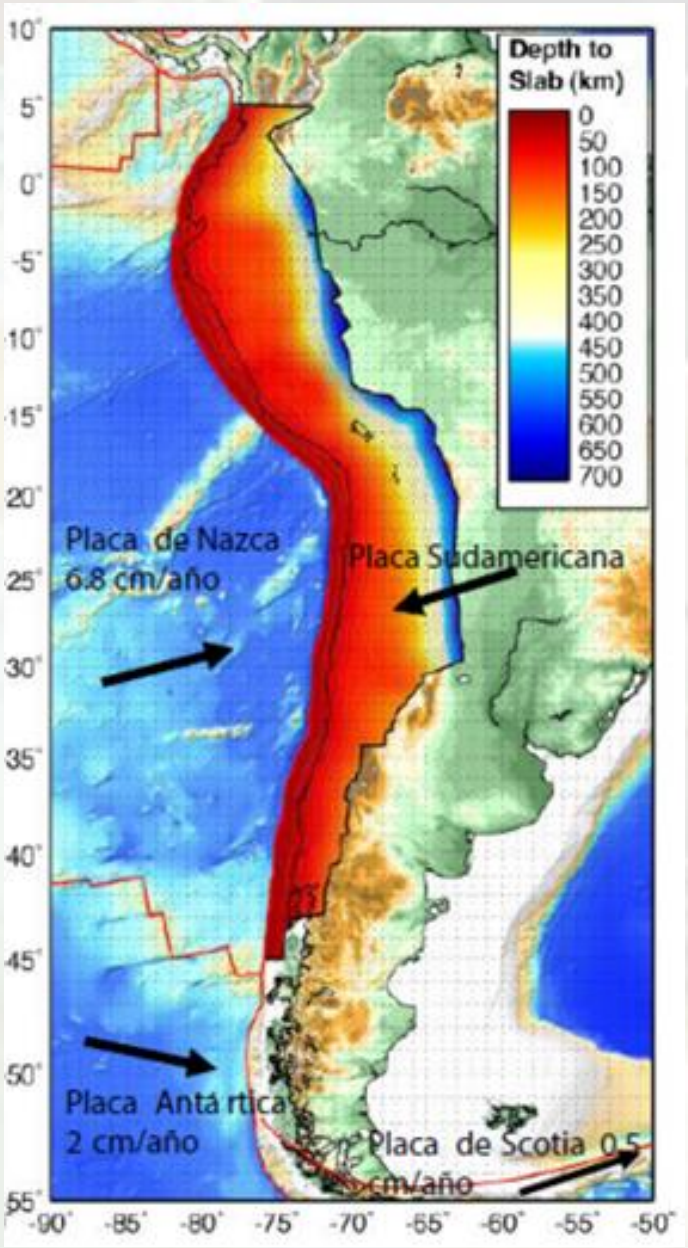
Horizontal Sliding

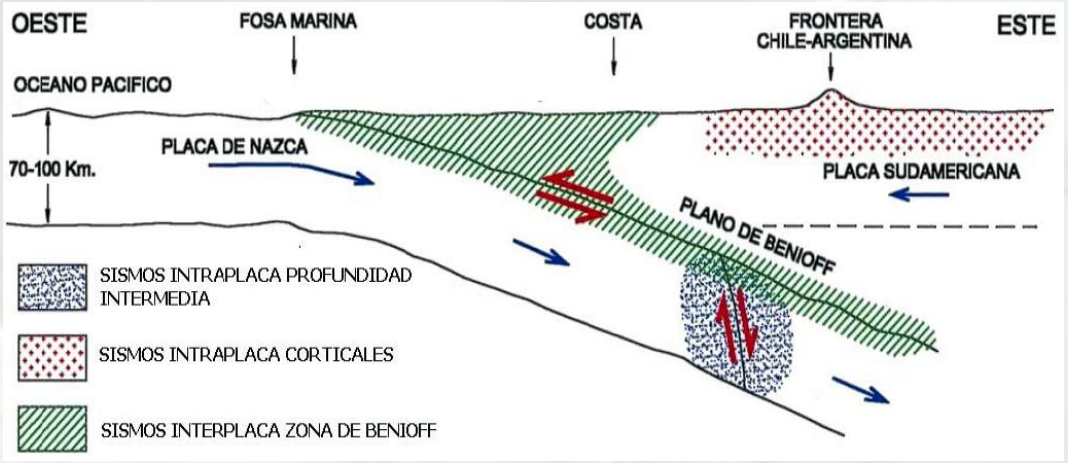
(HS)

Circumpacific Seismicity



Subduction Plate Interaction





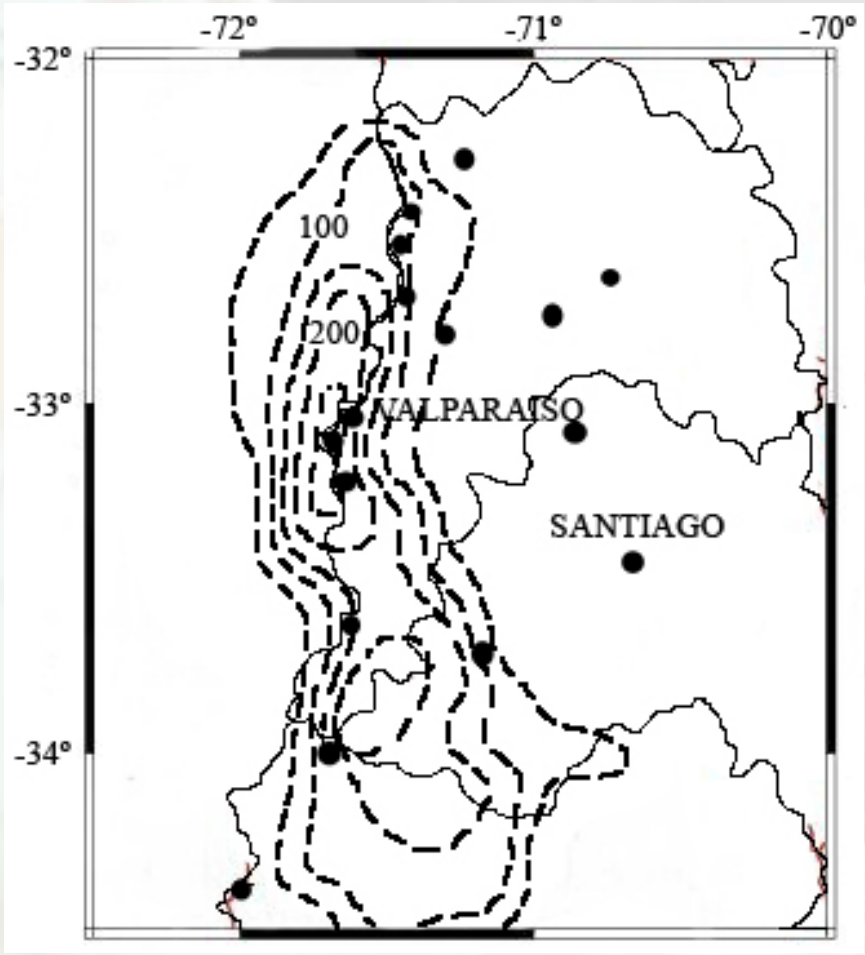
High seismicity

Large subduction interplate earthquakes

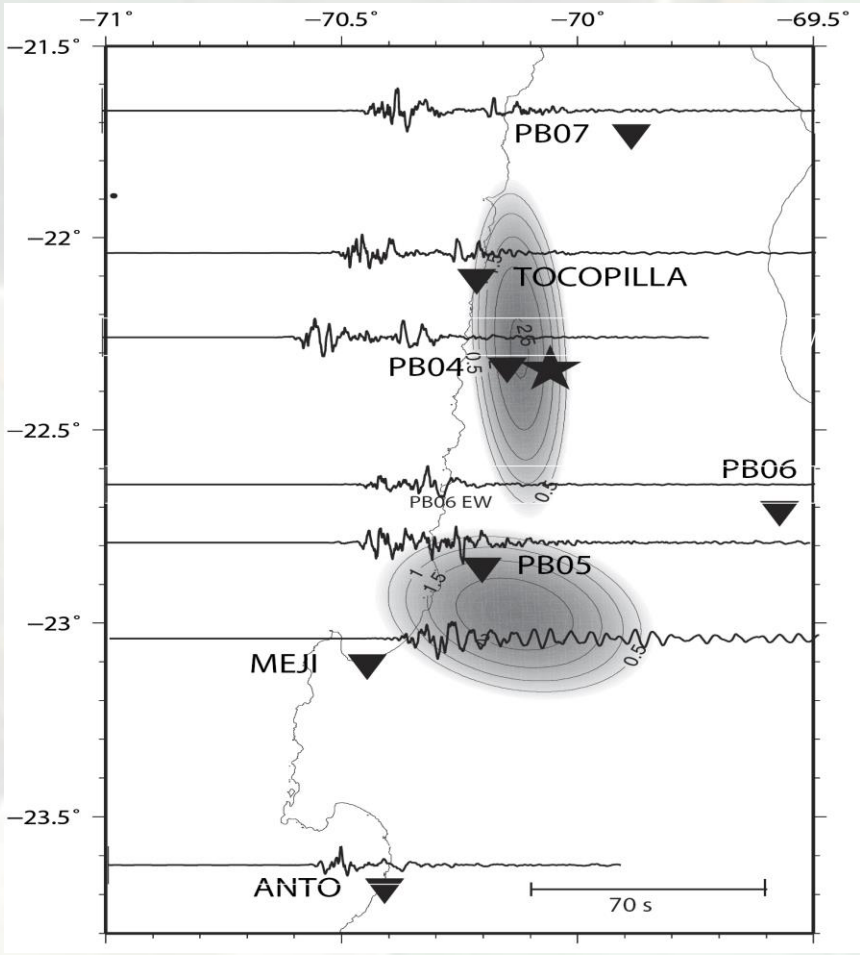
Off shore epicenters with large Tsunamis

Asperities in Northern of Chile

1985 - Algarrobo

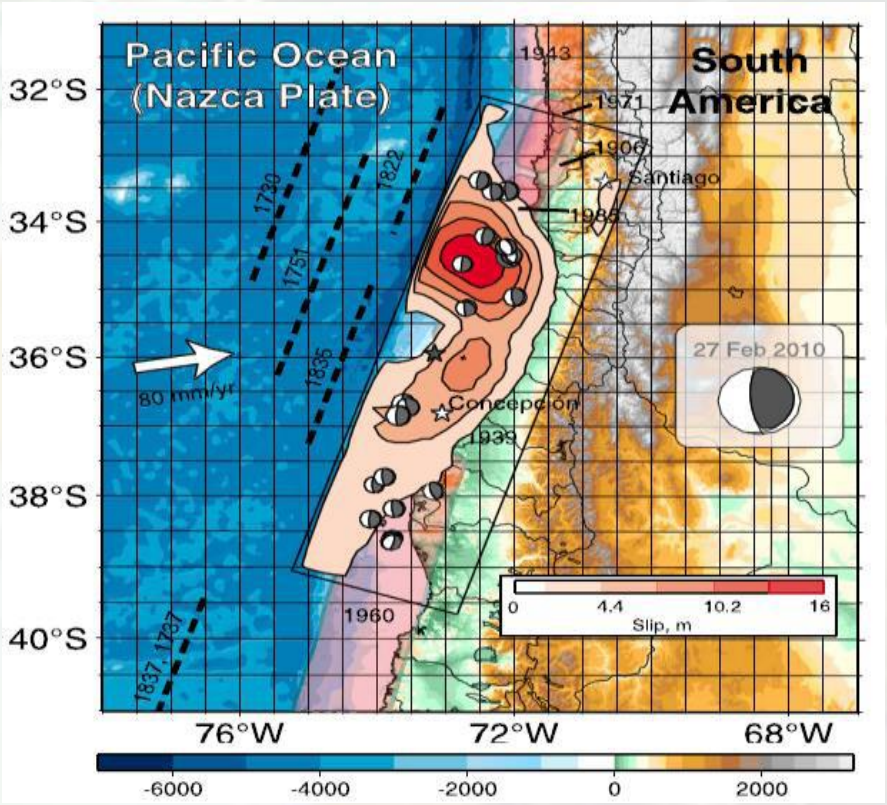


2007 - Tocopilla

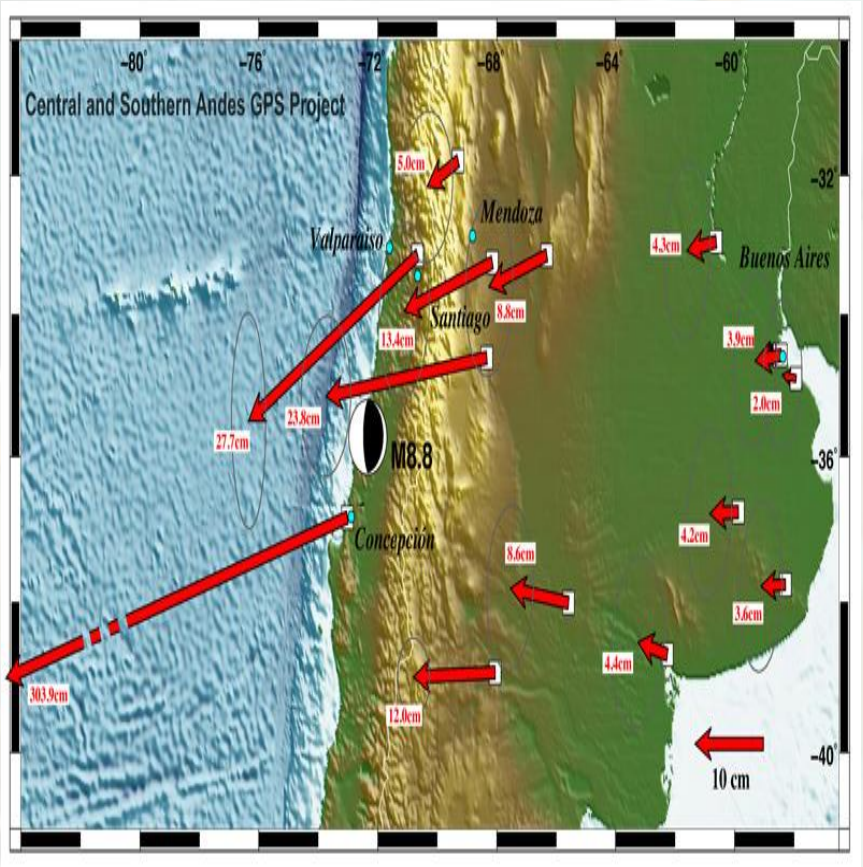


High levels of seismic energy at a few asperities on the subduction plate

February 27, 2010 (El Maule)



Asperities in Southern



GPS coseismic horizontal displacement

(303.9 centimetres at the coast, ENAP Refinery)

Chronology of Backward Studies

John A. Blume 1963, after 1960 Chile earthquake

Rinne 1967, after 1964 Alaska earthquake

Cooper 1997, for Earthquakes from 1933 to 1995

Pineda & Arze L. – Undergraduate Thesis 2000

Pineda, Saragoni and Arze L. - STESSA 2012

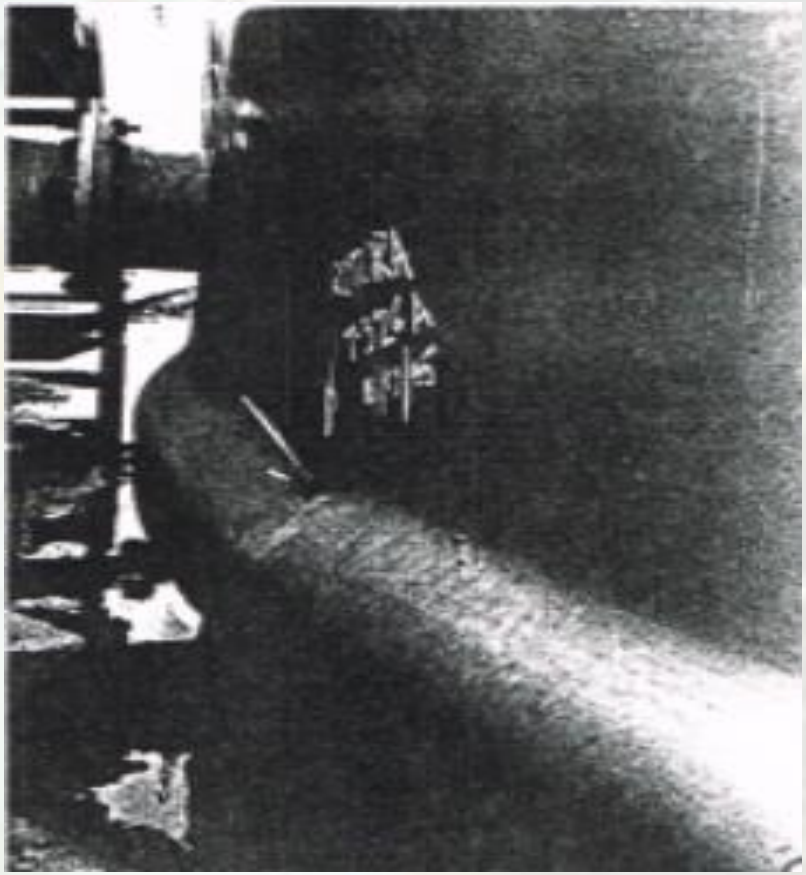
Pineda & Saragoni - STESSA 2015

Pineda & Saragoni - 16WCEE 2017

Pineda & Saragoni - M.Sc. Thesis 2017

Pineda & Saragoni - NCh2369 (Chilean Code) Upgrade (2016-2017)

Seismic Response – Con Con 1985



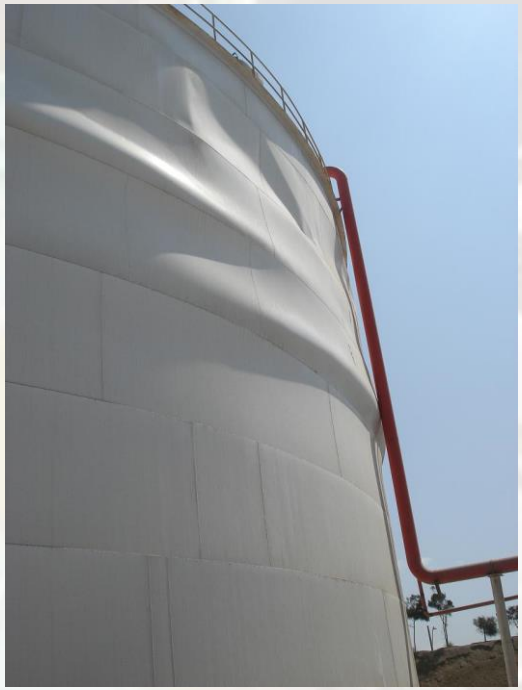
Buckling Shell (BS)

Observed Tanks Failures

Tank	D/ H_1	H_1	H_2	R_c (%)	Failure
T-326A	1.06	12.20	11.30	94.4	BSL
T-326B	1.06	12.20	11.30	92.6	BSL
T-418A	1.50	12.20	11.30	92.6	BSL
T-552 (1)	0.92	12.20	11.80	92.6	BSL
T-407A	1.12	12.20	11.60	92.6	BSL
T-320A	0.92	12.20	11.60	95.1	BSL
T-4001A	0.92	12.20	11.60	100	BSL
T-405A	1.50	12.20	11.60	95.1	BSL
T-420A	1.37	11.58	11.60	95.1	BSL
T-301A	1.56	9.75	9.20	95.1	BSL
T-422A	1.83	12.20	11.60	96.7	BSL
T-402	1.84	12.20	11.30	95.1	No Damage

Self – Anchored
Designed with API 650

Seismic Response – Tocopilla 2007



Buckling Shell

Uplift

Horizontal Sliding (±100mm)

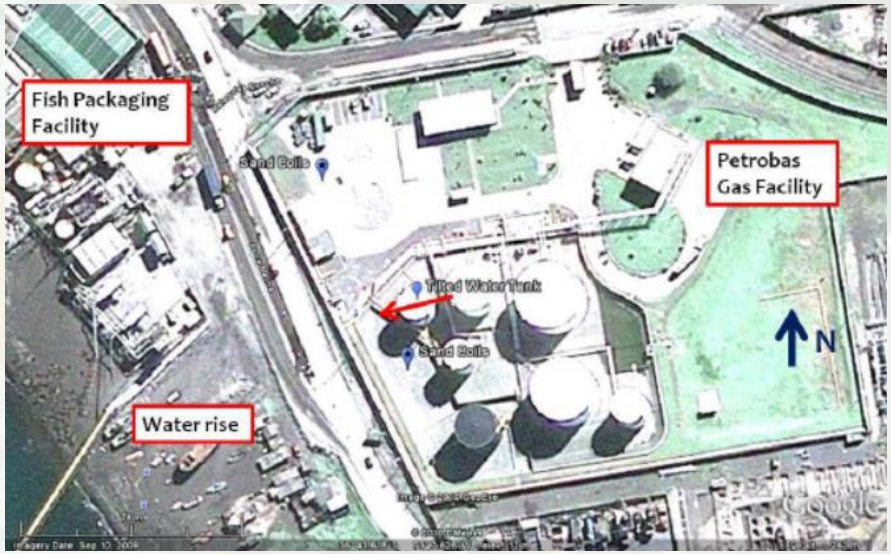
Requires Anchor Bolts

Seismic Response – Santiago 2010

Only collapse the self-anchored tanks

Rigid connections piping

Seismic Response – Port of San Vicente 2010



Tanks near epicenter

No evidence of damage

Tilted one degree

Seismic directivity

Seismic Response – Bío Bío 2010

Evidence of Sloshing

Must be controlled:
Height of Filling & Freeboard

Backward Seismic Analysis

Models do not reflect the real behavior in earthquakes, there is no correlation between:

Theoretical Models → Experimental Tests (Shaking Tables) → **The Observed Backward Analysis**

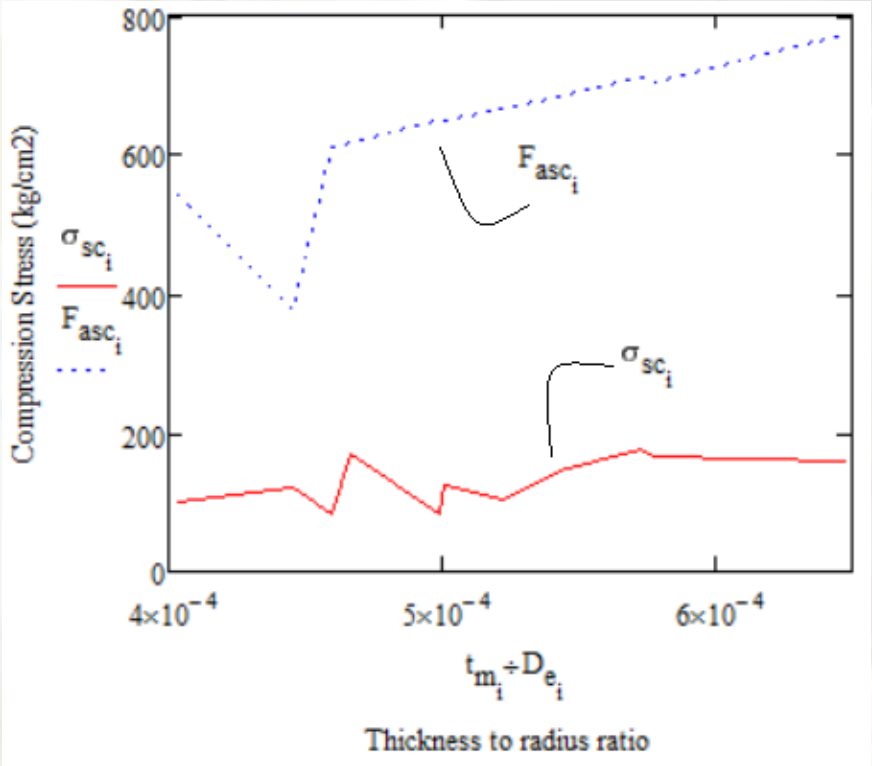
Repeated failures presented in large earthquakes

- **API 650-E: "Application of this standard does not imply that damage to the tank and related components will not occur during seismic events"**

Backward Seismic Analysis

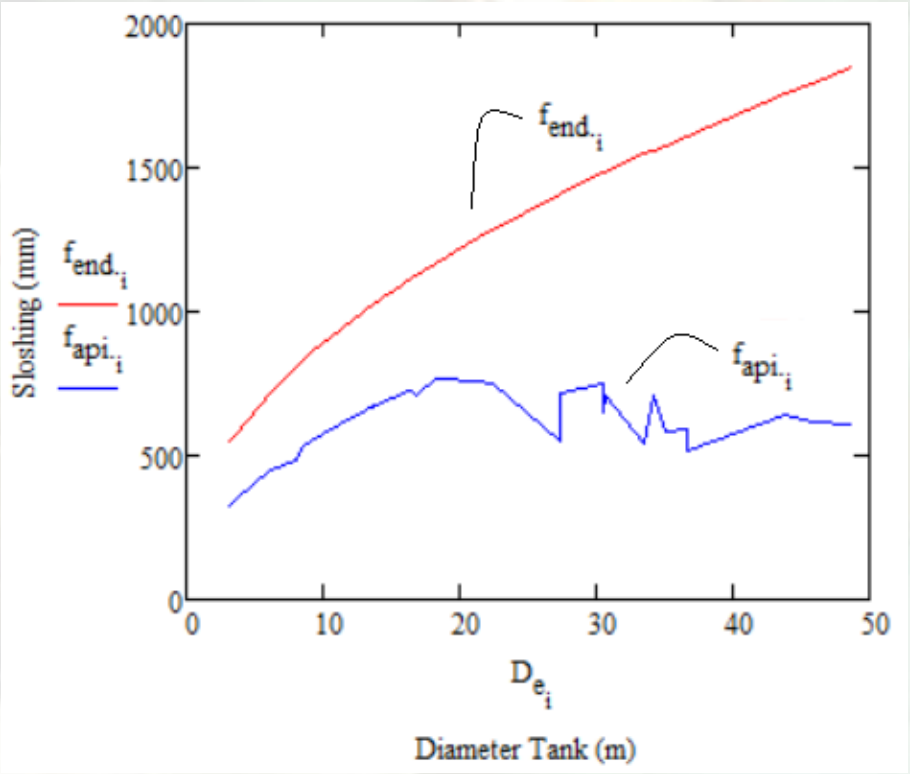
1985 earthquake

Shell compression



Underestimation with API650-E

Freeboard



Differences between codes

Cases Studies in Subduction Zones

Earthquake	Location	Mag.	Quantity	Content	Failure
Chile 1985	Algarrobo	7.9	12	G, N, So, Fo, Sp, A, K	BSL, U
Chile 2007	Tocopilla	7.7	1	Sa	BSU, HS
Chile 2010	El Maule	8.8	7	Sa, W, MT, G, D, T	U, CL,
Alaska 1964	Anchorage	9.2	24	W, O, Tf,	CL, RD, CB, BSL, BSU, U, BL, HS
Alaska 1964	Nikiski	9.2	7	W	CL, BSL, RD, U
Alaska 1964	Seward	9.2	1	Fo	BSL, B

Content: (G)Gasoline, (N)Nafta, (So)Solvent, (Fo)Fuel Oil, (Sp)Slop, (A)Asphalt, (K)Kerosene, (Sa)Sulfuric acid, (W)Water, (MT)Metil ter butyl eter, (D)Diesel, (T)Tar (alquitran), (O)Oil, (Tf)Turbine Fuel

Failure: (BSL)Buckling Shell Lower (type "elephant foot"), (U)Undamaged, (BSU)Buckling Shell Upper, (HS)Horizontal Sliding, (CL)Collapse, (RD)Roof Damages, (CB)Columns and Beams damages, (BL)Bottom Lift, (B)Burning.

Backward Seismic Analysis (BSA)

Evaluation of seismic response in Chile (65 cases):

1960 – 1985 – 2007 – 2010

Extensive information on seismicity and damage records in Chile allows to develop Backward Seismic Analysis

Required records:

- Seismicity
- Dimensions
- Soil type
- Design codes
- Damages
- Fill height

Methodology:

- Evaluation of seismic demand
- Shell compression
- Freeboard (Sloshing)
- Horizontal sliding
- Spectra for design, from BSA

Horizontal Sliding in Self-Anchored Tanks

On coastal of subduction zones, in terms on magnitude:

$$S[m] = -5.47 + 0.76M \;;\; M \geq 7.3 \text{ (Pineda \& Saragoni)}$$

Results in meters

In the perpendicular direction to the coast or in the convergence of the subducted plate.

Behaviour observed in earthquakes:

Earthquake	Magnitude	Plate Fault	S (mm)
Alaska 1964	9.2	Subduction	1524
Tocopilla 2007	7.7	Subduction	70-80
Landers 1992	7.3	Cortical	80-100

Final Comments

- To observ real performance of Steel tanks is only posible with Backward Seismic Analysis
- In Chile there was no failure because most of the tanks were anchored
- Large sliding are due to ground coeseismic displacement measured by GPS in coastal áreas
- Coseismic sliding in perpendicular direction to the coast or convergence of the subducted plate
- Proposed formula to estimate horizontal sliding of self-anchored tanks

THANKS FOR YOUR KIND ATTENTION

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