BACKWARD SEISMIC ANALYSIS OF STEEL TANKS

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GENERAL TOPICS

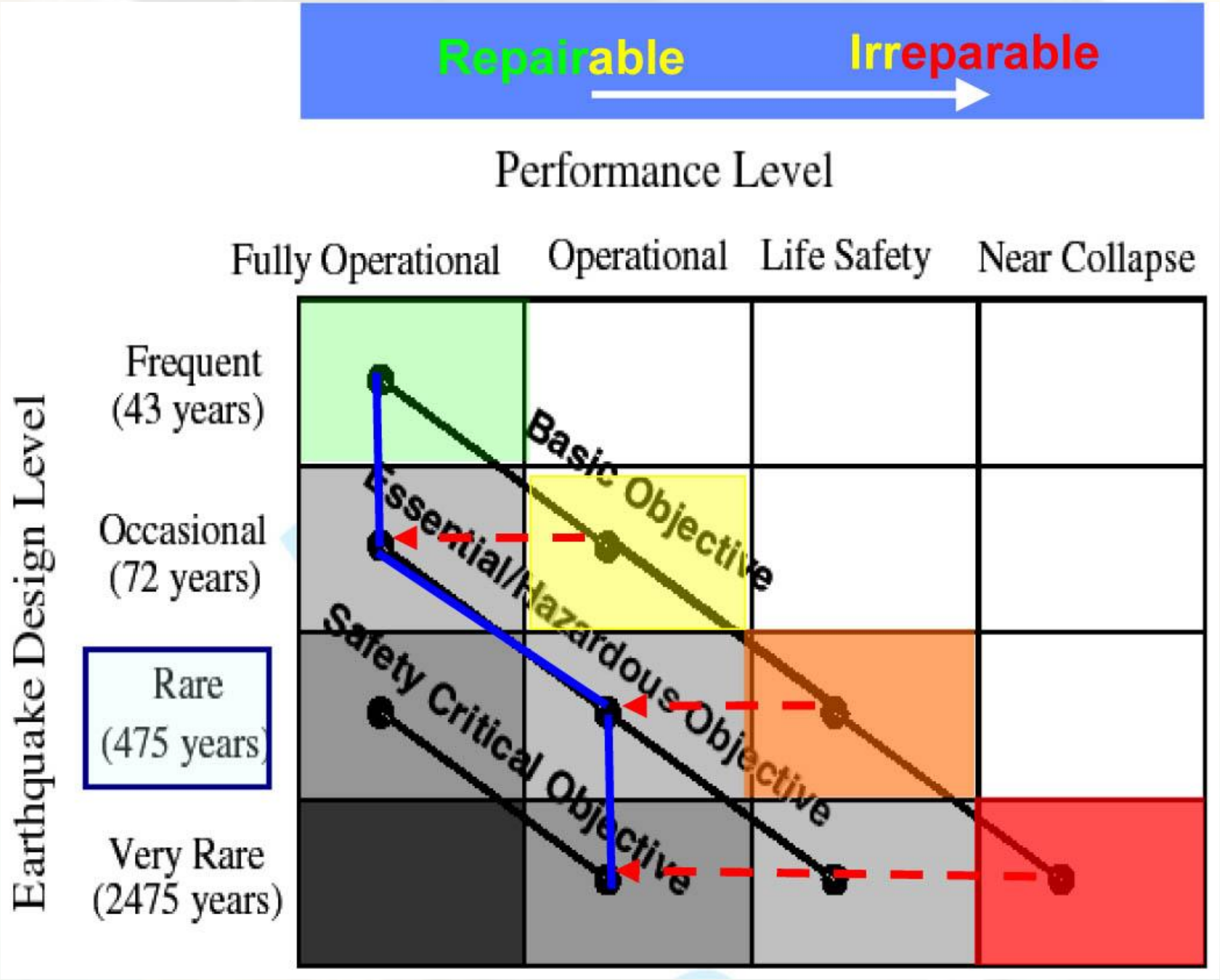
- Non-Building Structures
- Seismic Performance of Steel Tanks
- Seismic Activity
- Backward Analysis
- Performance During Chile Subduction Earthquakes
- Seismic Horizontal Sliding of Self-Anchored Steel Tanks
- Conclusions

NON-BUILDING STRUCTURES

Distinctive Aspects

“Buildings: Life Safety for People”

“Non-Buildings: Continuity of Operation in Industry“



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

Relevant Aspects

In the last earthquakes is not satisfied the continuity of operation

Frequent shutdowns in oil plants

Most structures are designed with codes

Is no time for repairs after earthquake

Design codes do not serve their purpose

Tanks Category

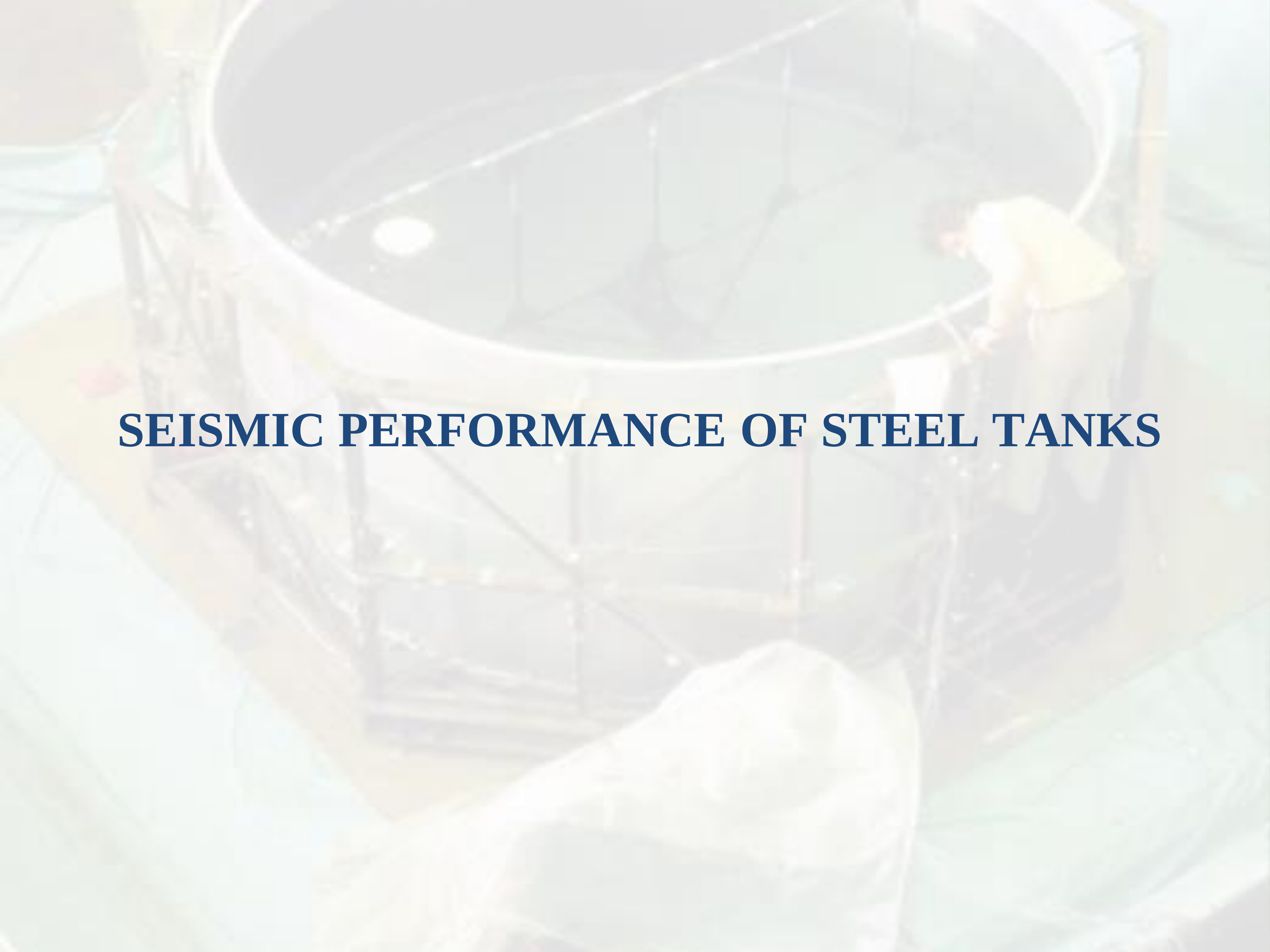
Mainly used in petrochemical plants and other industrial facilities

Irregular distribution of mass in height

Different values of damping according to seismic mass type (impulsive and convective)

Self-supporting structure (not anchored)

Gravity loads be required to resist effects of earthquake



SEISMIC PERFORMANCE OF STEEL TANKS

Characteristics

Petroleum, Liquefied Gas, Sulphuric Acid, Water Storage

Anchored

Self-anchored

Observed Tanks Failures on Earthquakes

Earthquake	Mag.	Principal Failures						
		RS	BS	WR	CB	RP	AB	HS
Chile 1960	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
Hokkaido 1993	7.6		X					X
Northridge 1994	6.7	X	X		X	X	X	X
Observed Failures (%)		50	100	17	50	50	33	83

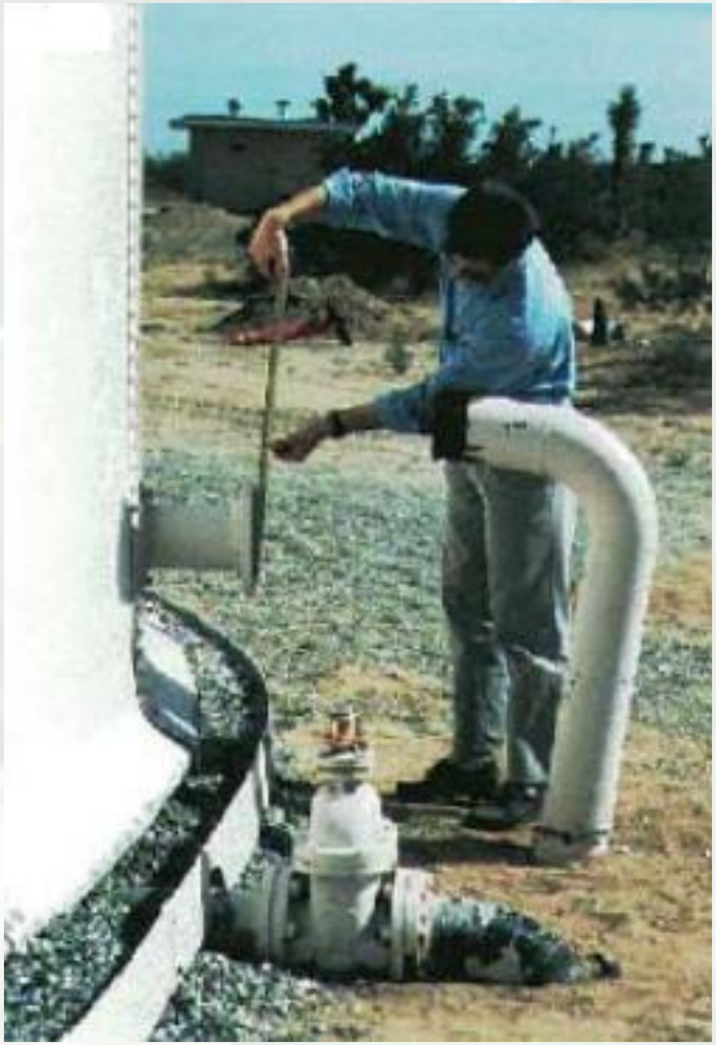
Rupture of Shell Wall : RS	Rupture in Roof Plates : RP
Buckling of Shell Wall (foot of elephant) : BS	Rupture of Anchorage Bolts : AB
Failures in Joints Wall – Roof : WR	Horizontal Sliding : HS
Failures in Columns and Beams : CB	

(Pineda (2000))

Main fails are buckling Shell and horizontal sliding

Observed Tanks Failures on Earthquakes

Buckling Shell



Horizontal Sliding

Other Damages – Japan Earthquake (2011)

Collapsed by the Tsunami

Burned-out gasoline tank

Comments

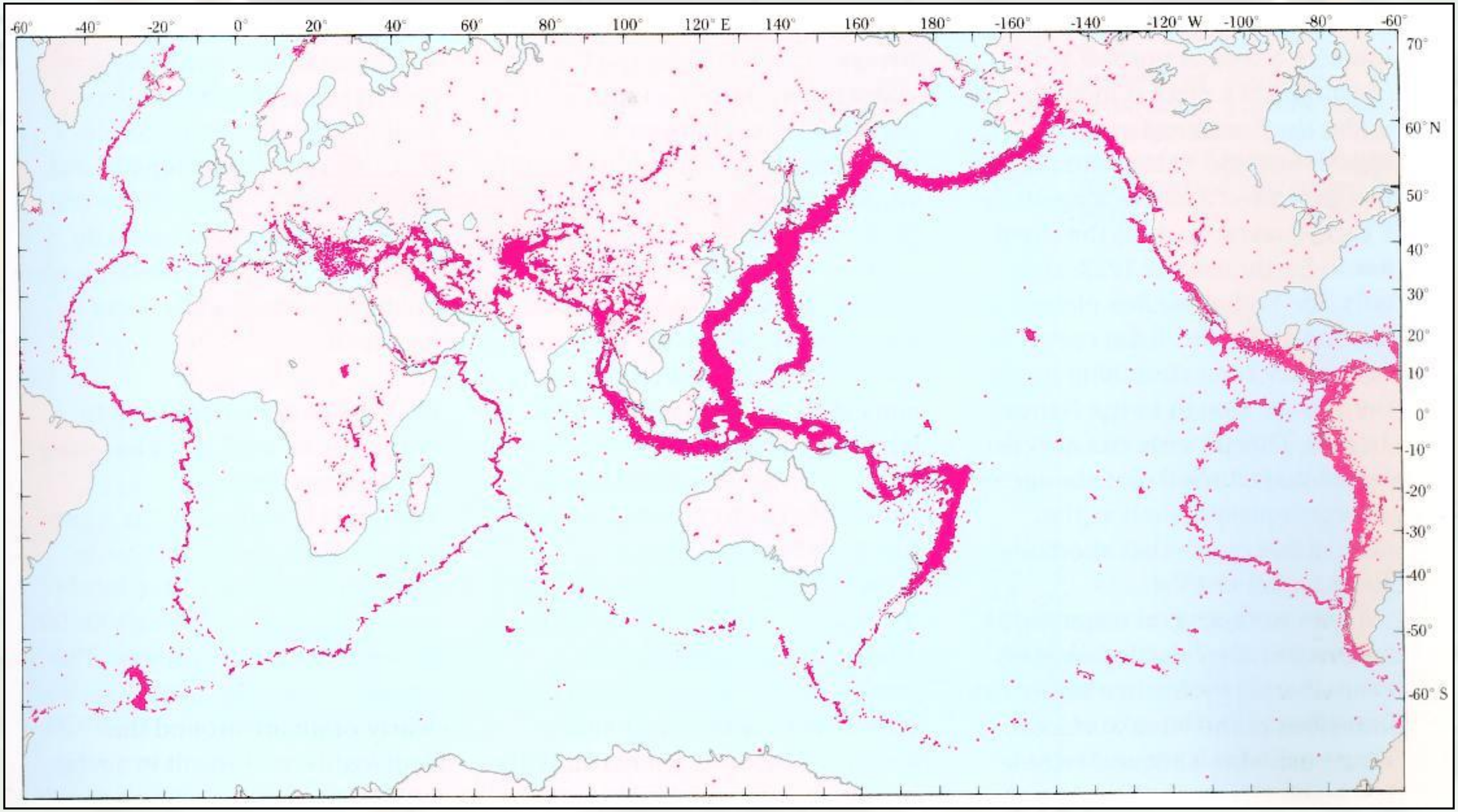
Presented repeated failures in large earthquakes

Being design with codes: API650-E, AWWA D100, NZSEE and Chilean Code NCh2369

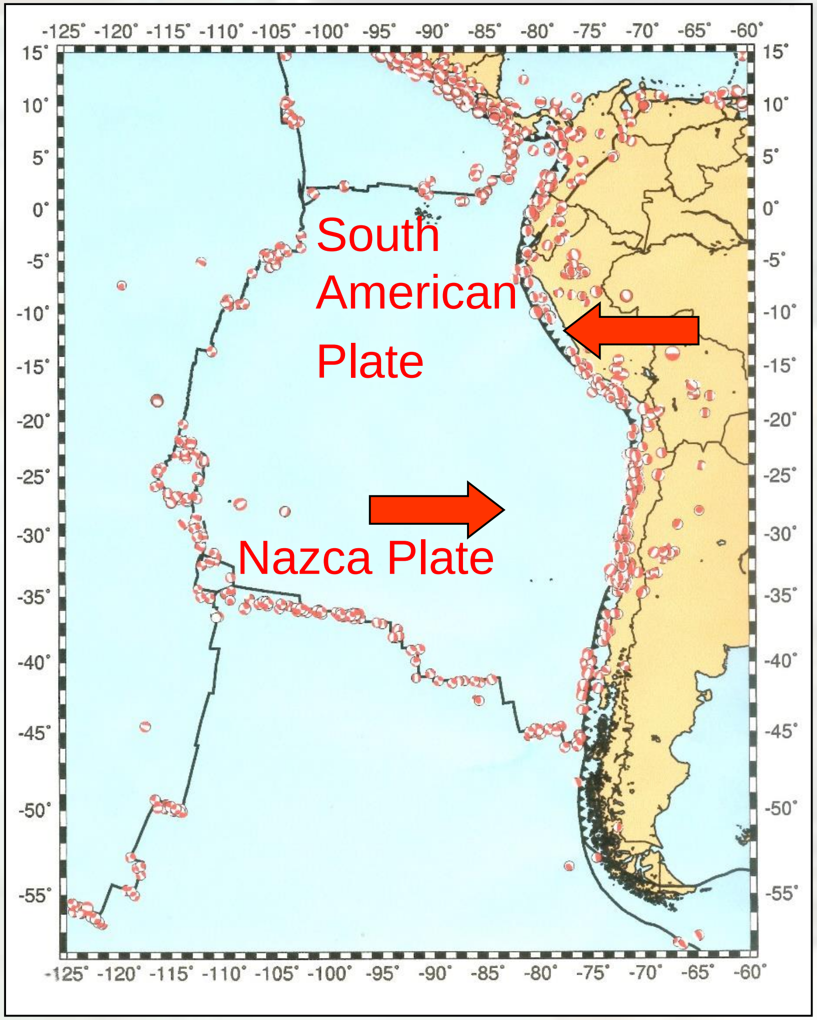
It is necessary a better understanding of seismic response to improve existing code

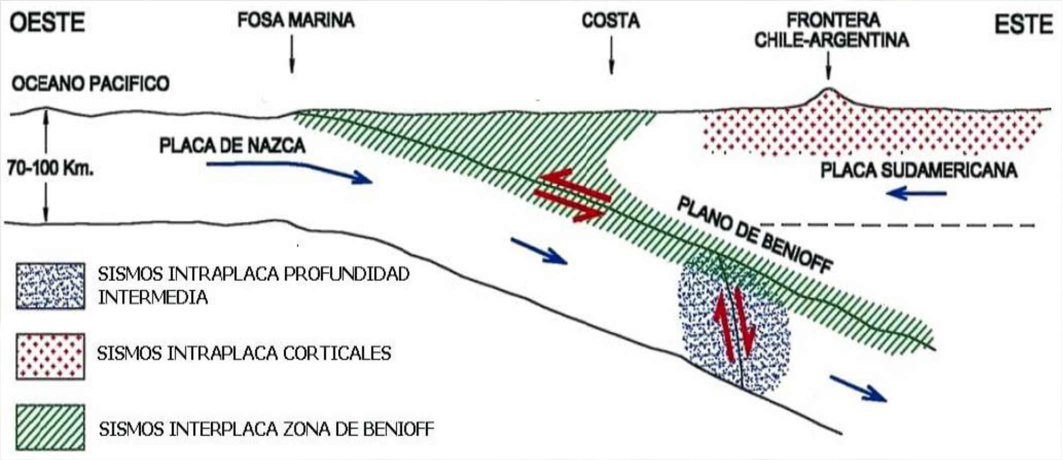
SEISMIC ACTIVITY

Circumpacific Seismicity



Subduction Plate Interaction

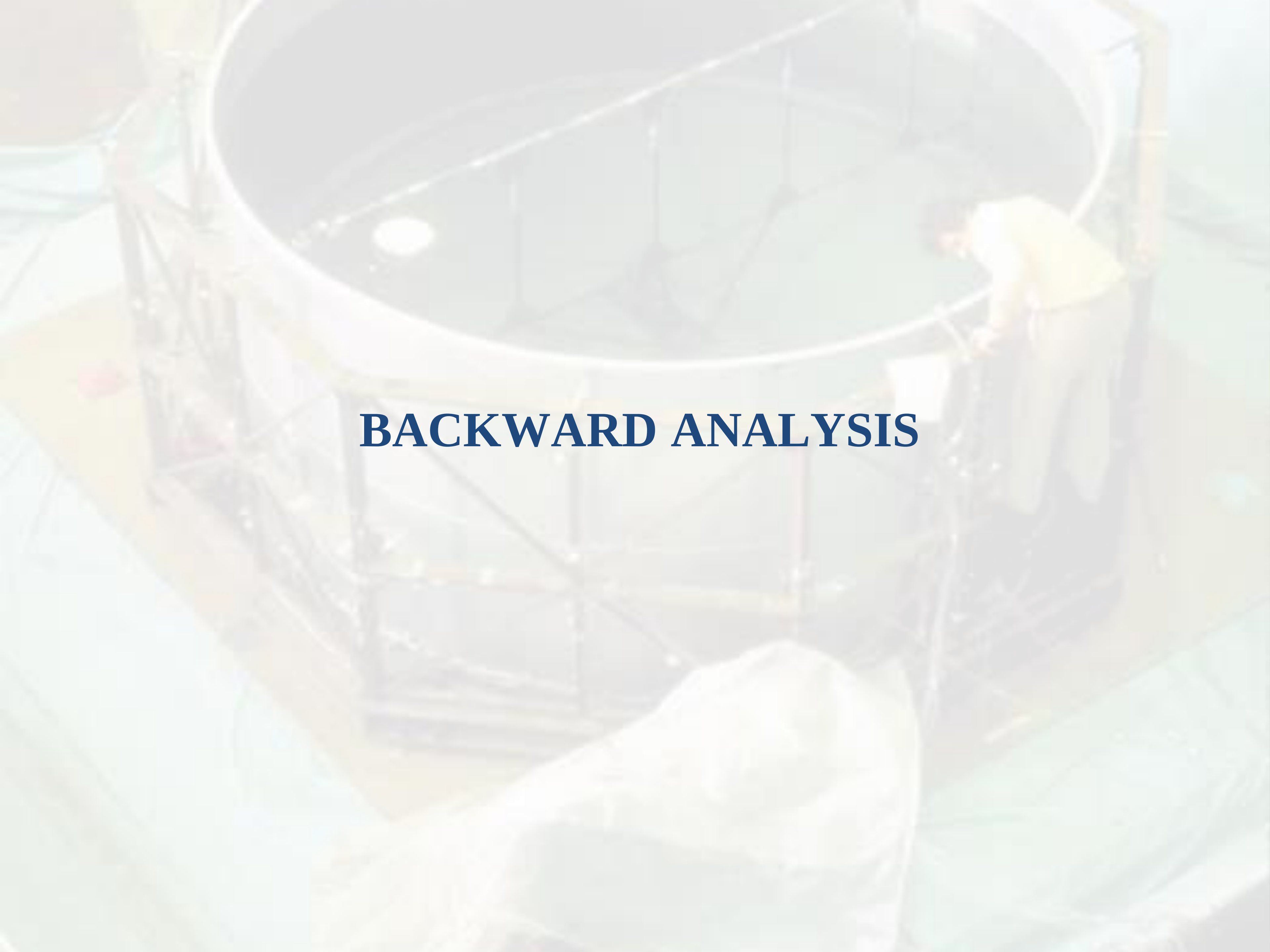




High seismicity

Large subduction interplate earthquakes

Off shore epicenters with large Tsunamis



BACKWARD ANALYSIS

Chronology of Backward Studies

Rinne 1967, after Alaska earthquake

Cooper 1997, for Earthquakes from 1933 to 1995

Pineda & Saragoni, STESSA 2012

Pineda & Saragoni, STESSA 2015

Mains Aspects

Observed performance of real tanks during large earthquakes

Comparing results with theorical or code recommendations

Understand the reason of the poor performance of codes

Required Characteristics:

- Geometry
- Anchorage conditions
- Properties of the liquid
- Fill Heights
- Damages
- Soils foundations
- Seismic Ground Accelerations

Characteristics of Tanks in Major Earthquakes

Thomas W. Cooper Study (1997)

Earthquake	Mag.	Mech. of Faulting	Distance to Fault[2]	Epicentre Distance	Failure	Soil Type[1]	Fluid Level (earthquake)
Long Beach 1933	6.4	Cortical	2-5km	3.5-45km	BS/AB/RS	N/I[1]	Full
Kern County 1952	7.5	Cortical	N/I[1]	3.2-42km	BS	Alluvial	Full
Chile 1960	9.5	Subduction	N/I[1]	N/I[1]	BS	Sand[5]	N/I[1]
Alaska 1964	9.2	Subduction	N/I[1]	130km	BS/HS	Silt-Clay	Full
San Fernando 1971	6.7	Cortical	N/I[1]	21km	AB/BS	N/I[1]	(1/2-2/3)H
Armenia 1972	7.0	Cortical	N/I[1]	N/I[1]	BS	N/I[1]	N/I[1]
Imperial Valley 1979	6.5	Cortical	4-5km	30km	RS	Rock	Full
Coalinga 1983	6.7	Cortical	N/I[1]	6.5km	BS	N/I[1]	3/4H
Loma Prieta 1989	6.9	Cortical	N/I[1]	40km	RS	Alluvium	Full
Landers 1992	7.3	Cortical	100km	N/I[1]	BS/HS[4]	N/I[1]	N/I[1]
Hokkaido 1993	7.6	Subduction	N/I[1]	80km	BS	Poor	N/I[1]
Northridge 1994	6.7	Cortical	Near	8km	BS	Rock	Full
Kobe 1995	6.9	Cortical	2-4km	10km	Tilting	(3)	N/I[1]

(1) N/I: no information available
(2) Tectonic Plates
(3) Liquefaction
(4) Horizontal sliding: 80mm
(5) Compacted sand filling

PERFORMANCE DURING CHILE SUBDUCTION EARTHQUAKES

Central Chile Earthquake 1985

Epicenter Off Shore in front the Algarrobo City

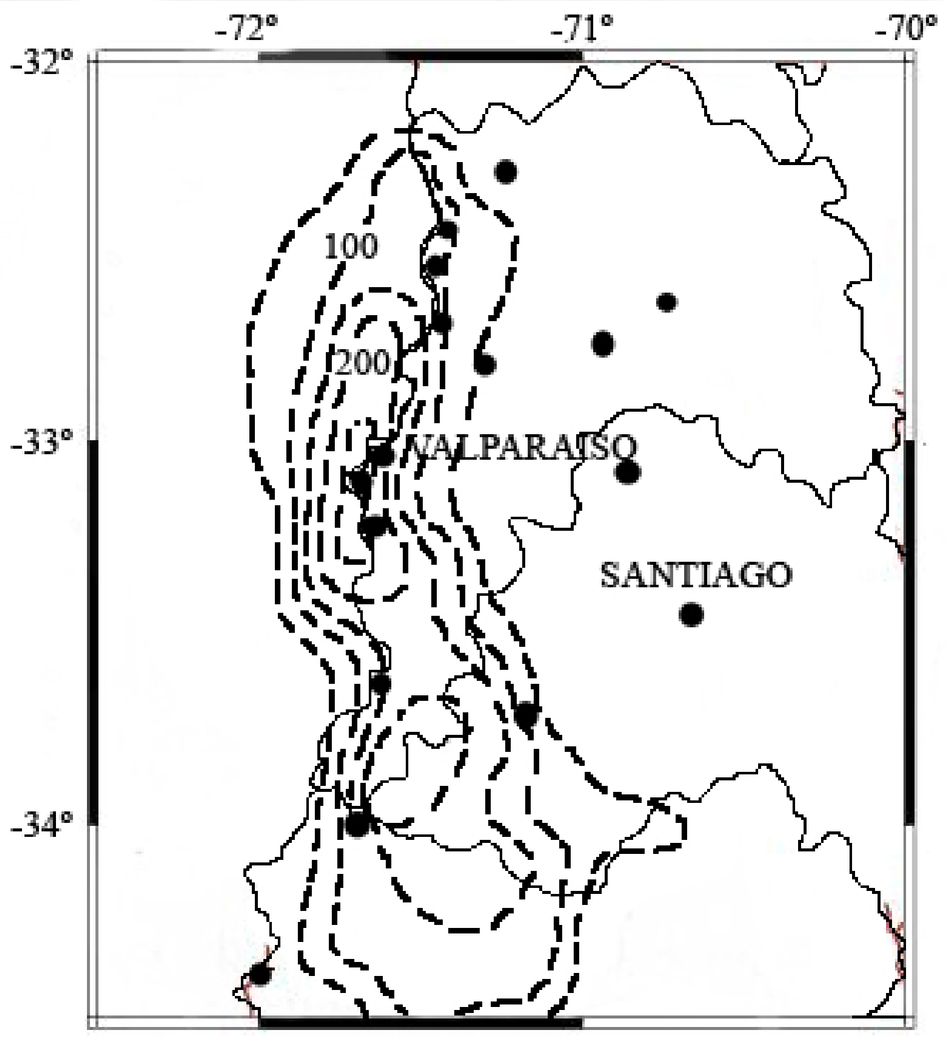
Mag. = 7.8

PGA_h = 0.67g

PGA_v = 0.81g

Central Chile Earthquake 1985

At least two large zones of asperities (modified from Barrientos (1988))



Observed Tanks failures on ENAP Refinery

Tank	R (m)	H (m)	H_1 (m)	H_2 (m)	Product	Fail
T-326A	6.48	12.2	11.30	10.61	Gasoline	BS
T-326B	6.48	12.2	11.30	11.20	Gasoline	BS
T-418A	9.14	12.2	11.30	11.23	Nafta	BS
T-552 (1)	5.59	12.2	11.80	11.56	Solvent	BS
T-407A	6.86	12.2	11.60	11.56	Fuel Oil	BS
T-320A	5.59	12.2	11.60	10.42	Fuel Oil	BS
T-4001A	5.59	12.2	11.60	11.15	Slop	BS
T-405A	9.14	12.2	11.60	11.33	Asphalt	BS
T-420A	7.92	11.58	11.60	1.94	Kerosene	(2)
T-301A	7.62	9.75	9.20	3.26	Kerosene	(2)
T-422A	11.17	12.2	11.60	7.88	Kerosene	(2)
T-402	11.20	12.2	11.30	10.80	Gasoline	(3)

H_1: Maximum height of the liquid (sloshing).
H_2: Filling height at March 3, 1985.
(1) Tank more damaged only with break in joint bottom shell, with loss of stored liquid.
(2): Slight deformation.
(3): Undamaged.

All tanks were self-anchored

Mainly designed according to API 650-E

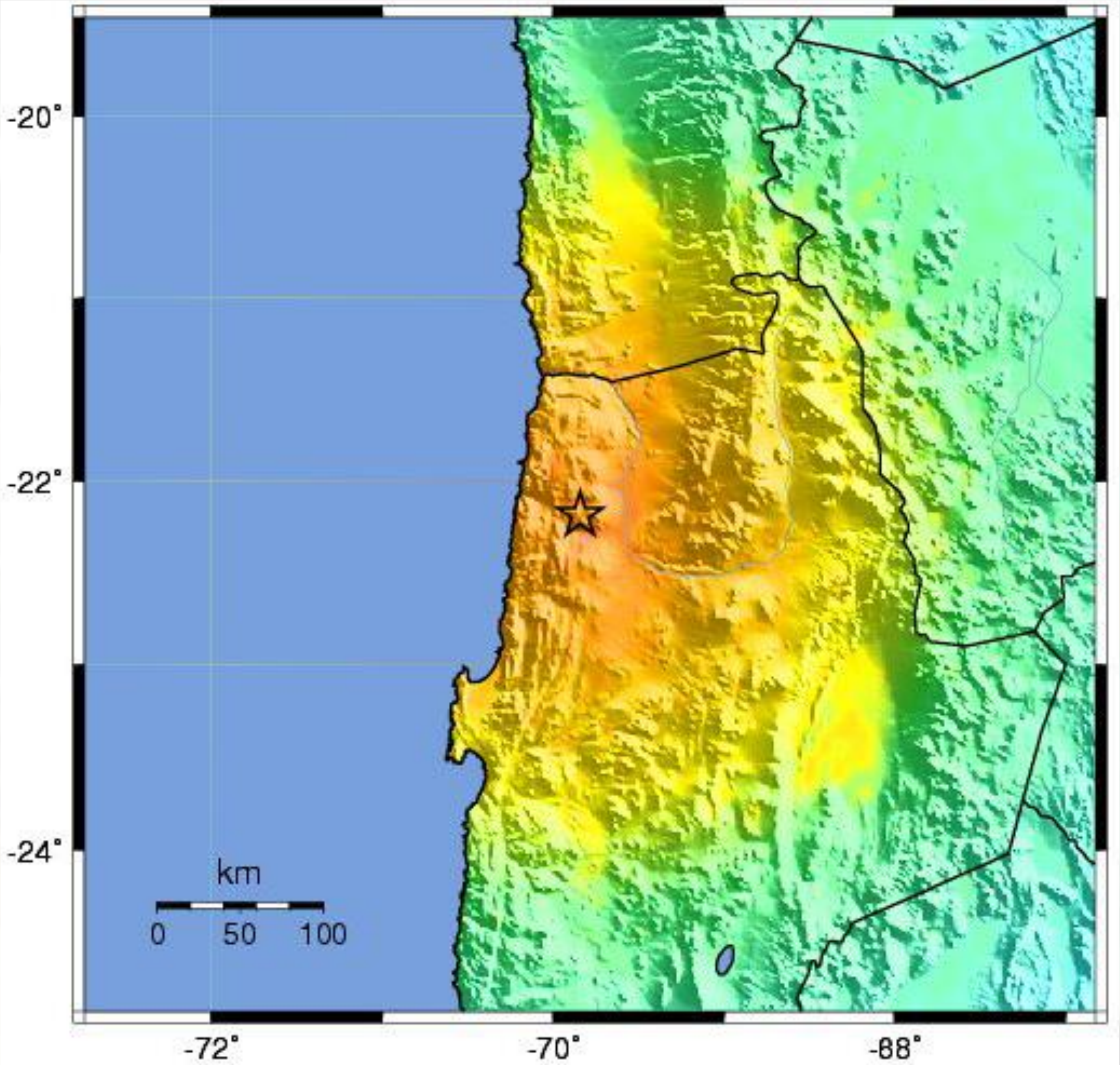
Tocopilla Earthquake 2007

Mejillones

Mag. = 7.7

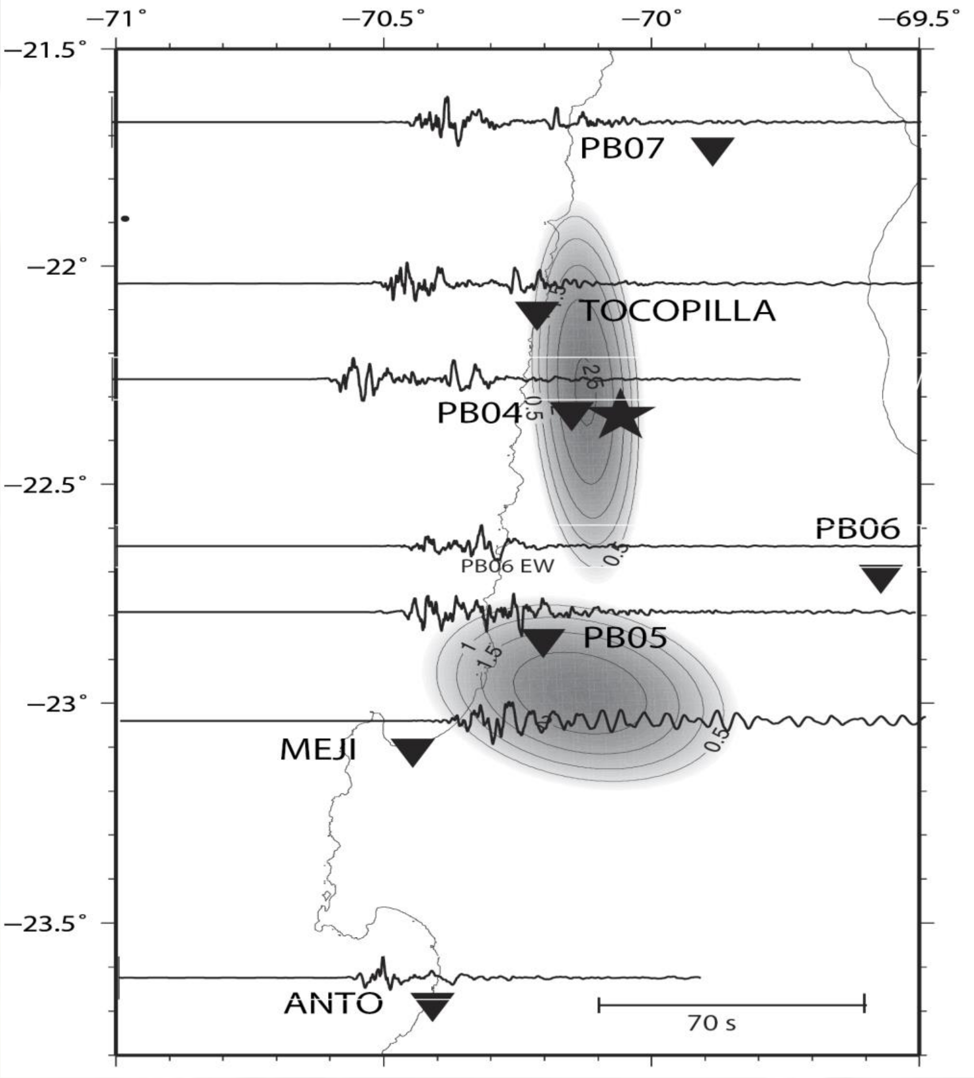
PGA_h = 0.42g

PGA_v = 0.36g



Tocopilla Earthquake 2007

At least two large zones of asperities. South asperity at Mejillones location.



Tocopilla Earthquake 2007

Buckling "elephant foot", lifting of base of 80mm

Horizontal sliding (100mm) in perpendicular direction to the coast, in convergence direction of subducted Nazca plate

El Maule 2010 Earthquake

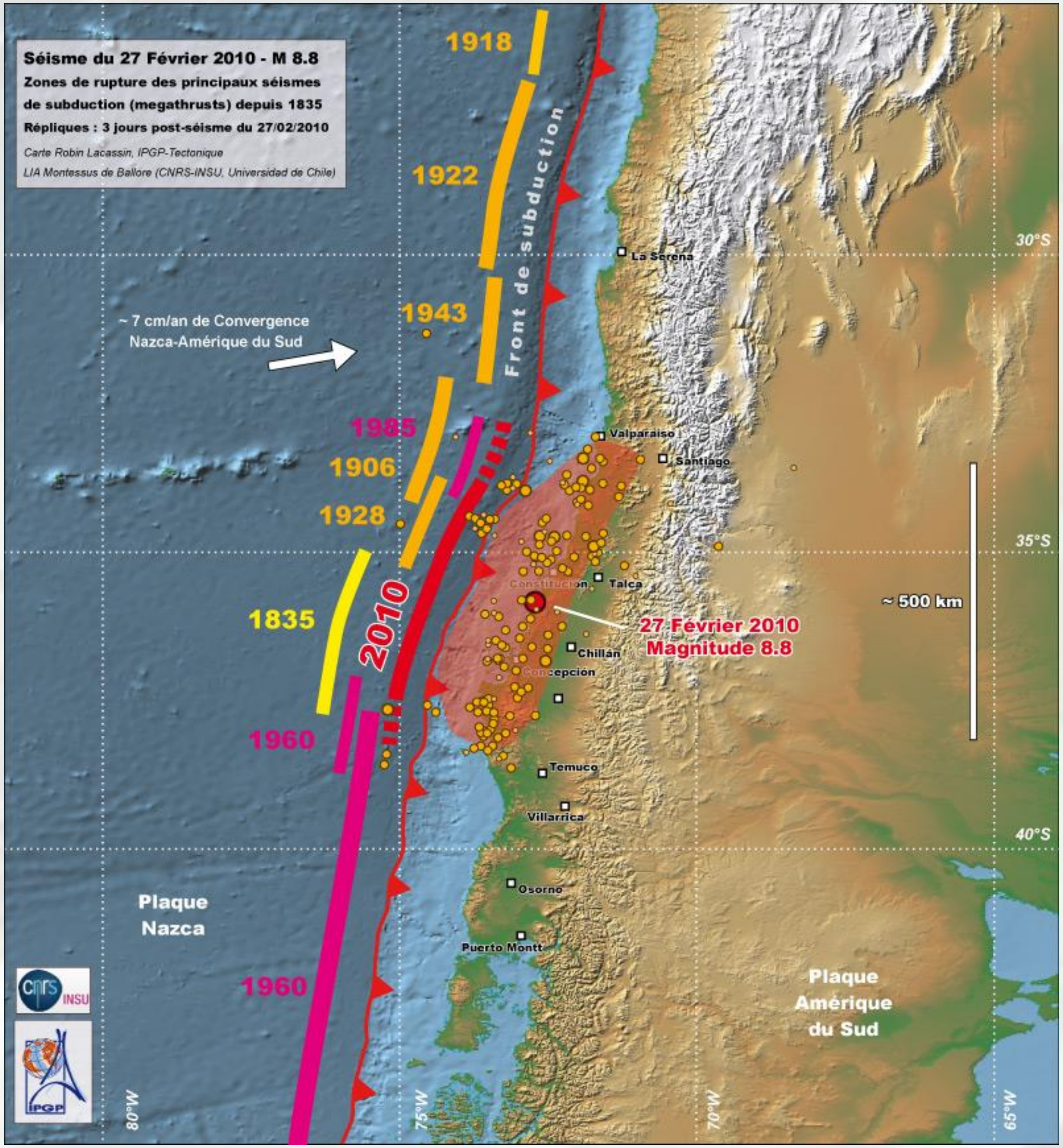
Off Shore in front of the coast of Maule

And Bio

Mag. = 8.8

$PGA_h = 0.93g$

$PGA_v = 0.69g$



El Maule 2010 Earthquake

Observed Tanks on ENAP Bio refinery

Designed according to NCh2369.Of2003

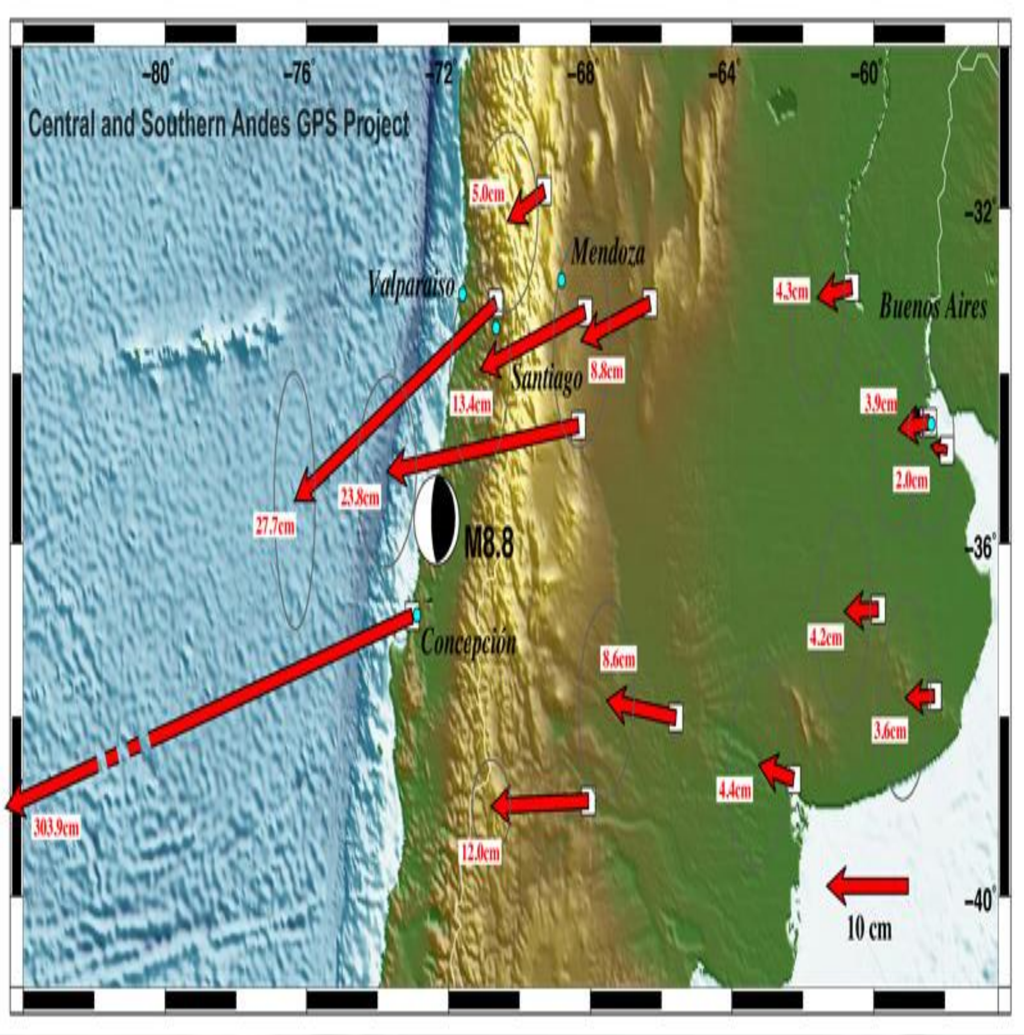
Minor damages specifically in three floating roof tanks

Spilled oil

Lateral spreading and soil liquefaction

El Maule 2010 Earthquake

GPS coseismic horizontal displacement showing 303.9 centimetres at the coast (ENAP Refinery)



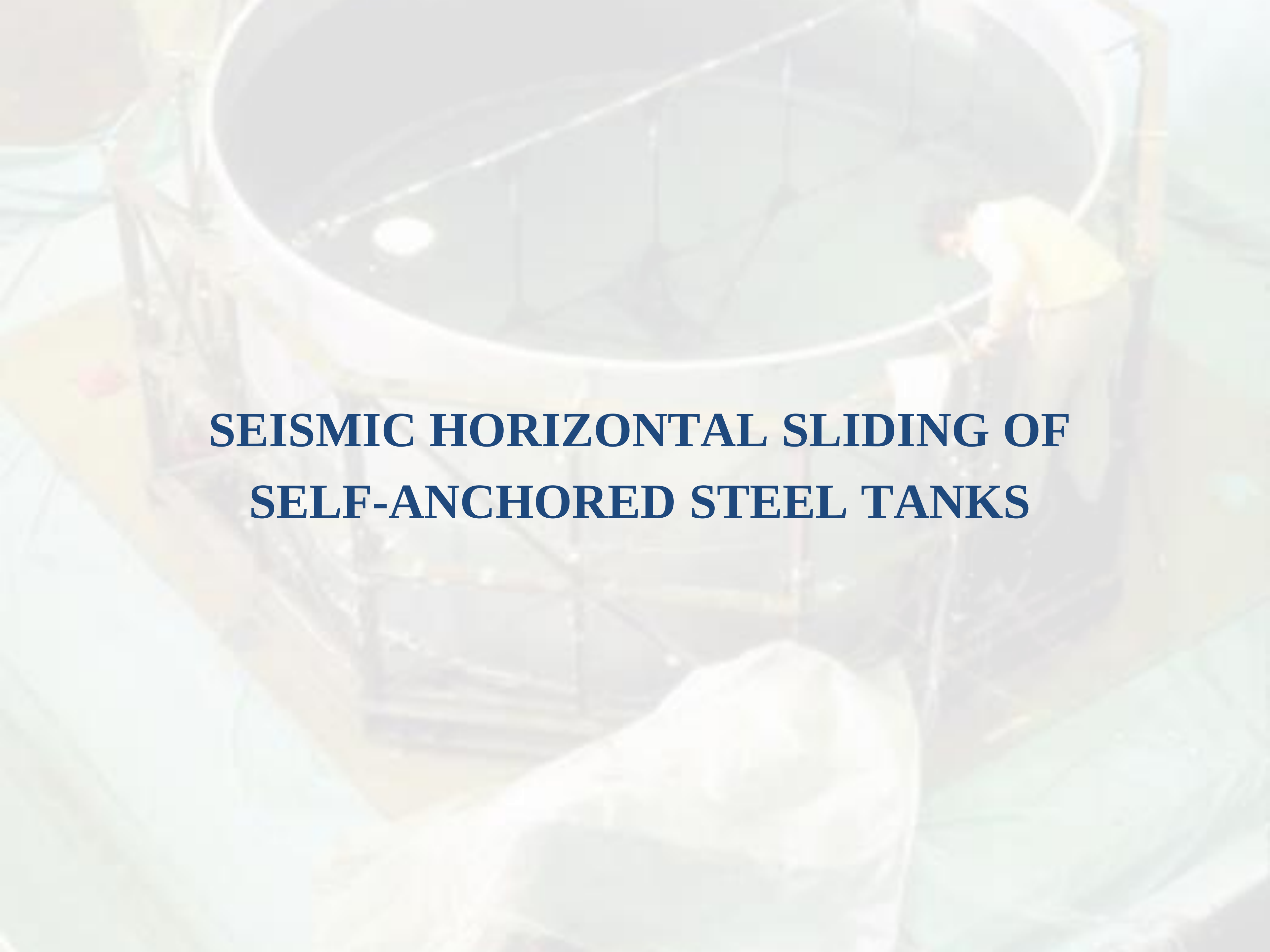
Comments

Earthquakes of subduction interplate type

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

In Chile there was no failure because the tanks were anchored mostly

Proposed formula to estimate displacement Sliding of Tanks



SEISMIC HORIZONTAL SLIDING OF SELF-ANCHORED STEEL TANKS

Principal Observed Horizontal Tanks Sliding

Earthquake	Magnitude	Plate Fault	Horizontal Sliding (mm)	D(m)	H(m)
Alaska	9.2	Subduction	1524	3.2	9.144
Tocopilla	7.7	Subduction	80	35	14.5
Landers	7.3	Cortical	70-80	16.5	7.3

These values are very large of the order of meters

Preliminary Formula to Estimate Sliding of Tanks

On coastal of subduction zones, in terms on magnitude:

$$S[m] = -5.47 + 0.76M \quad ; \quad M \geq 7.3$$

Results in meters

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

CONCLUSIONS

Conclusions

Backward analysis of tanks located in coastal areas

Studies of three large Chilean subduction interplate earthquake

Large sliding are due to ground coeseismic displacement measured by GPS in coastal áreas

Proposition of the formula for horizontal sliding of self-anchored tanks

Conclusions

The sliding in subduction earthquake is almost in the direction perpendicular to the coast or convergence of the subducted plate

Requires anchored tanks solutions, despite their geometry

Observed tanks functioned satisfactorily according to Chilean code NCh2369.Of2003

Using of anchors (uplift) and shear keys (sliding)

THANKS FOR YOUR KIND ATTENTION

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