PERFORMANCE OF STEEL TANKS IN CHILE 2010 AND 1985 EARTHQUAKES

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January 2012

DEDICATION

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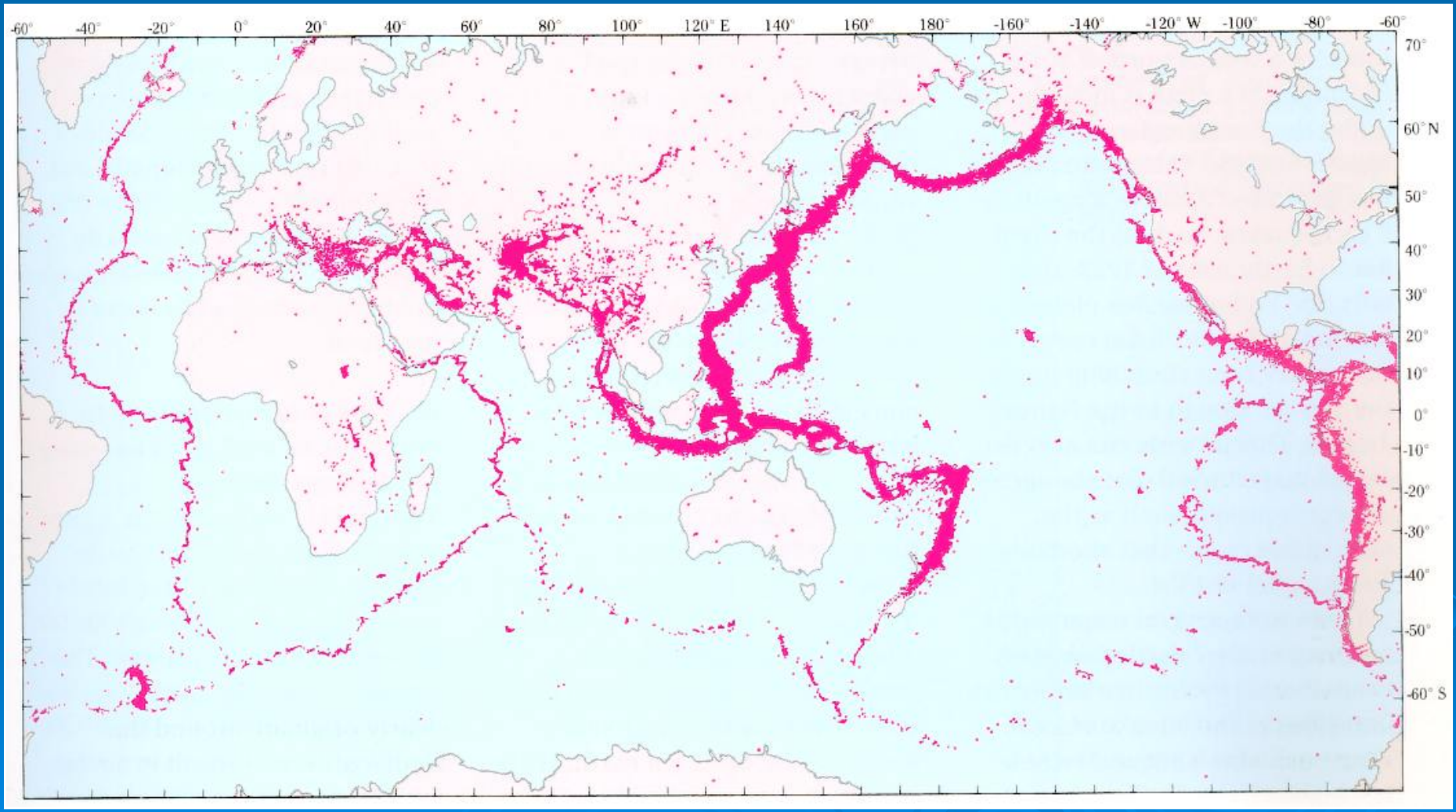
GENERAL TOPICS

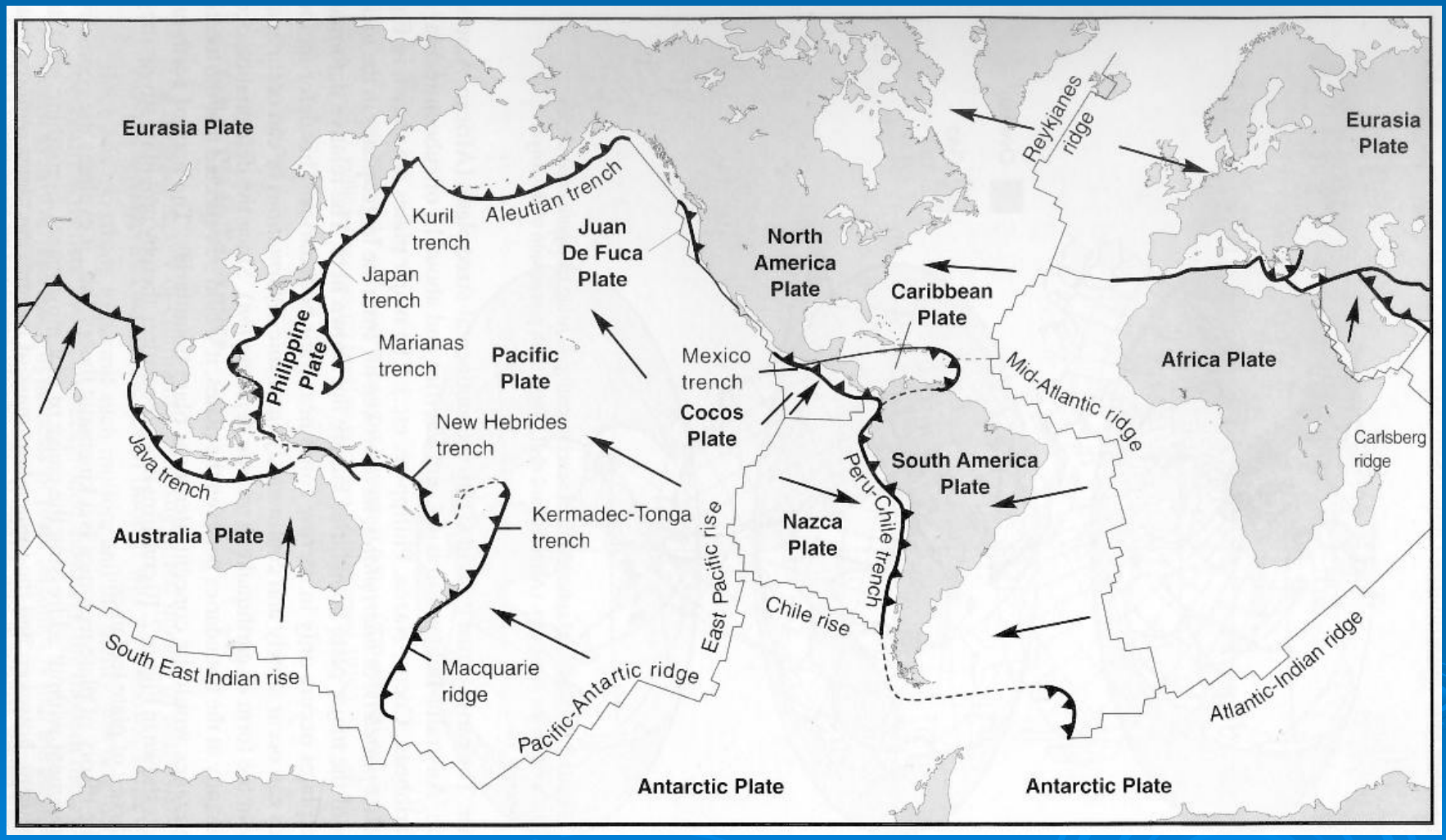
- Seismic Activity
- Main failures in Chile earthquakes with subduction:
  - February 27, 2010 : M=8.8
  - March 3, 1985 : M=7.8
- Comparison with main types of failures observed in major earthquakes worldwide
- Conclusions

SEISMIC ACTIVITY

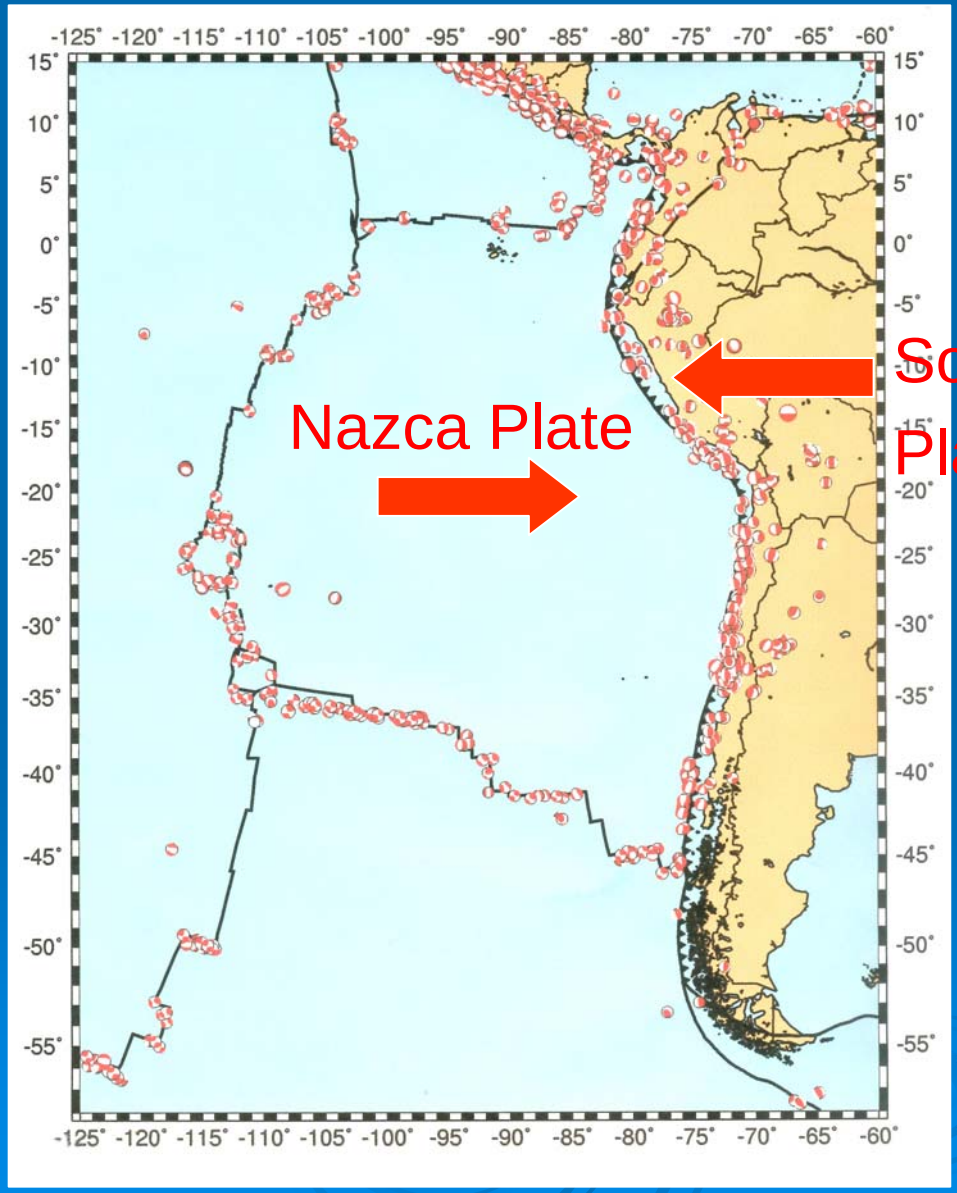
CIRCUMPACIFIC SEISMICITY



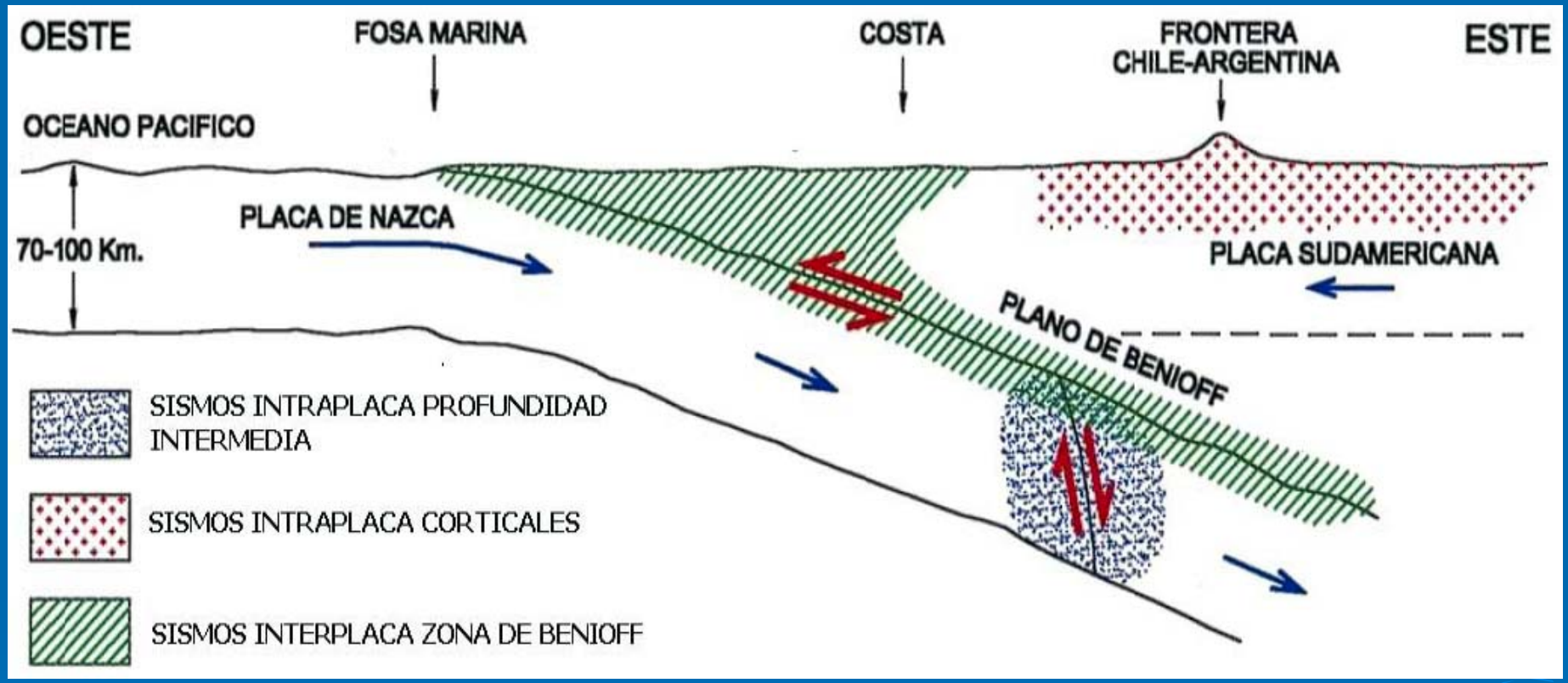
CIRCUMPACIFIC SUBDUCTION



SUBDUCTION OF NAZCA PLATE UNDER SOUTH AMERICA PLATE

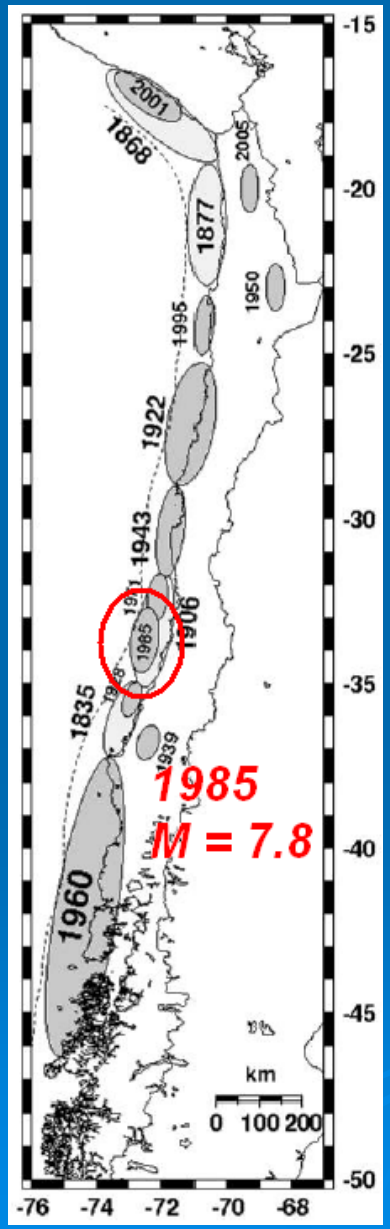


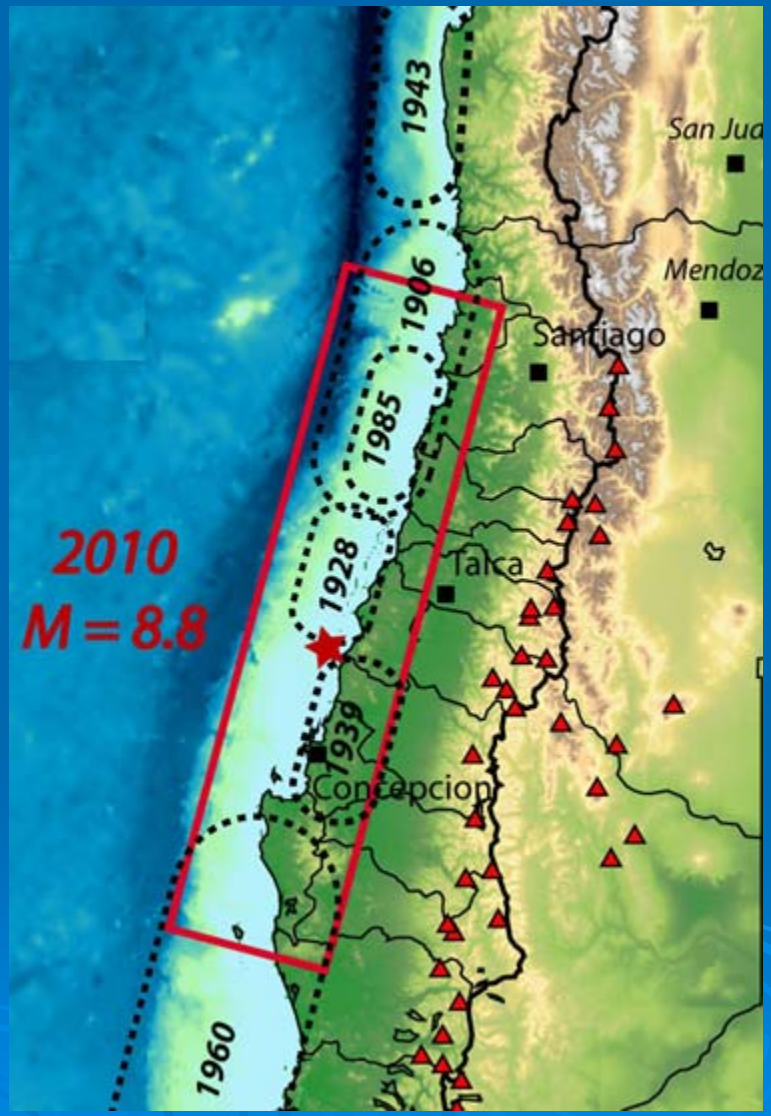
SUBDUCTION PLATE INTERACTION



- High seismicity
- Large subduction interplate earthquakes
- Off shore epicenters

RUPTURE AREAS OF EARTHQUAKES IN CHILE





2011 JAPAN EARTHQUAKE M=9.0

Similar to Chilean Earthquakes
With Subduction and Large Tsunami

MAIN FAILURES IN MAJOR EARTHQUAKES

PREVIOUS STUDIES

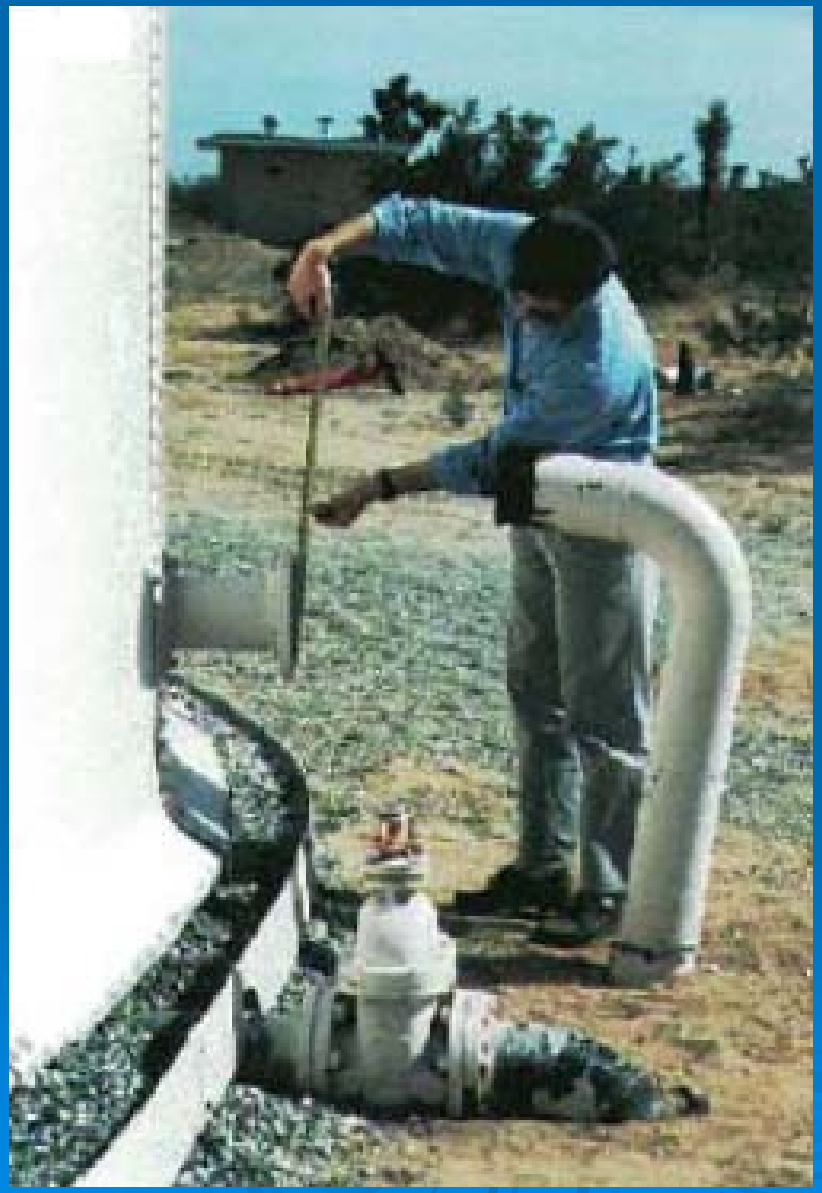
Table 1. Observed Tanks Failures on Earthquakes (Pineda (2000))

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
Buckling of Shell Wall (Foot of 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

BUCKLING SHELL – BS (100%)

HORIZONTAL SLIDING - HS (83%)



MOST FREQUENT FAILURES

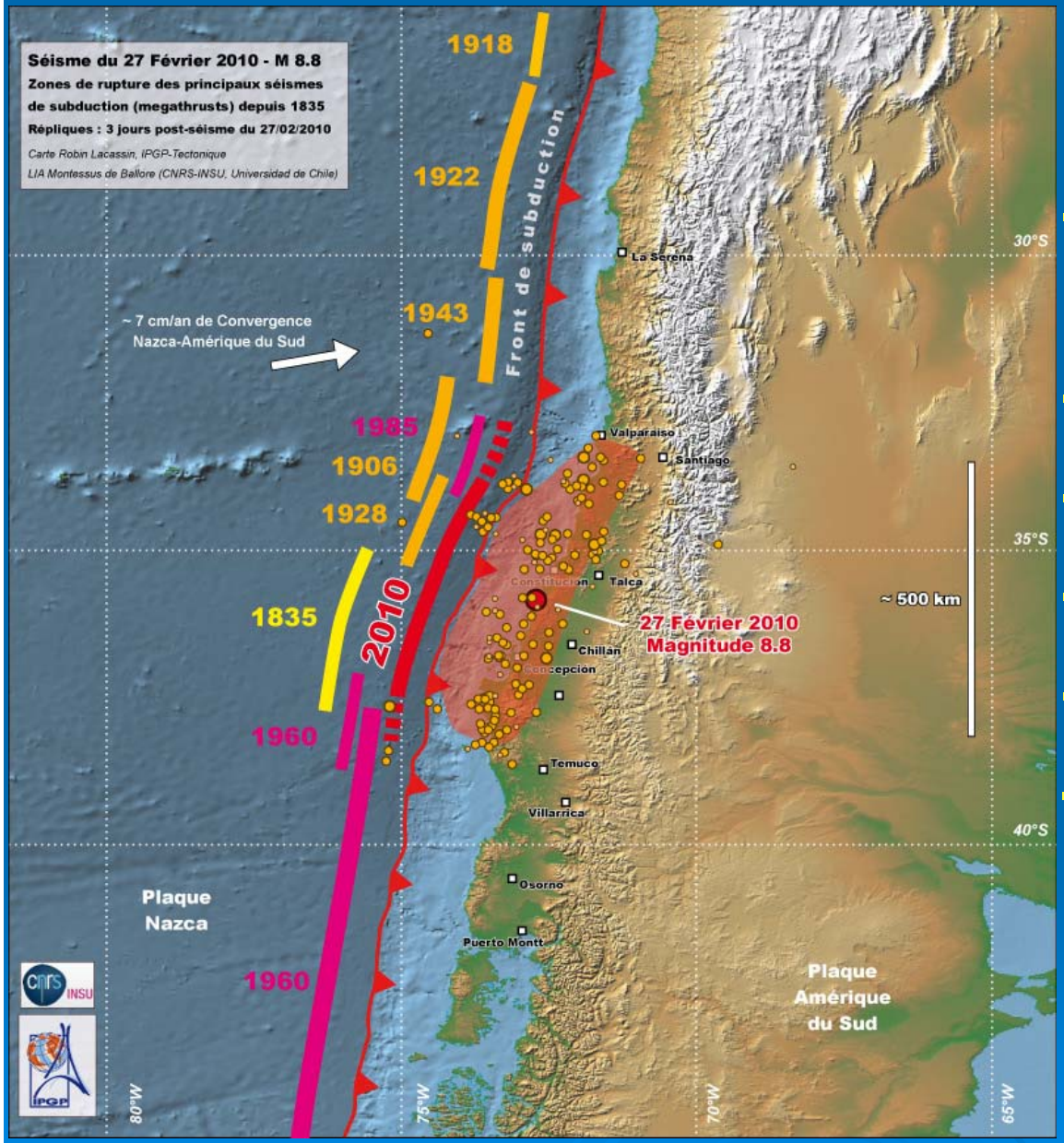
Rupture of Pipes

Failures in Joints Wall – Roof

COMMENTS

- Tanks shown above are self-anchored
- Mainly designed according to API 650-E (1980)
- Must be review design criteria for self-anchored tanks

2010 CHILE EARTHQUAKE



- Off the Coast of Maule and Bio Bio
- M=8.8
- PGA_h=0.93g
- PGA_v=0.69g
- Duration: 2'45''
- With Large Tsunami

SANTIAGO INTERNATIONAL AIRPORT

- Capacity: 1300m^3
- Collapse
- Self-Anchored
- Full when earthquake occurred
- We assume design problems
- Undamaged tanks near
- -- Far away from the epicenter

SANTIAGO INTERNATIONAL AIRPORT

SANTIAGO INTERNATIONAL AIRPORT MASONRY DROP FORCE WATER

PORT AT CONCEPTION AREA
TILTED ONE DEGREE

Near the Epicenter

COMMENTS

- Tank performed well due to use mechanical anchor recommended by NCh2369.Of2003 Chilean Standard
- Steel tanks were located in industrial and oil zones of Chile
- Seismic recorders were located near the epicenter

1985 CHILE EARTHQUAKE

- Epicenter off city of Algarrobo
- M=7.8
- PGA_h=0.67g
- PGA_v=0.81g
- Duration: 1’35’’
- Without Tsunami

Table 2. Tank Fails in 1985 Chilean Earthquake (Vera (1992)), Con Con RPC

Tank	H(m)	R(m)	V(m^3)	Product	Roof	Fail
T-326A	12.2	13	1600	Gasoline	Floating	BS
T-326B	12.2	13	1600	Gasoline	Floating	BS
T-418A	12.2	18.3	3200	Nafta	Floating	BS
T-552(1)	12.2	11.2	1200	Solvent	Floating	BS
T-407A	12.2	13.7	1792	Fuel Oil	Conical	BS
T-320A	12.2	11.2	1200	Fuel Oil	Conical	BS
T-4001A	12.2	11.2	1200	Slop	Conical	BS
T-405A	12.2	18.3	3200	Asphalt	Conical	BS
T-420A	11.6	15.9	2285	Kerosene	Conical	(3)
T-301A	9.8	15.2	1760	Kerosene	Conical	(3)
T-422A	12.2	22.4	4800	Kerosene	Conical	(3)
T-402(2)	12.2	22.4	4800	Gasoline	Conical	Without

(1) Tank more damaged only with break in joint bottom shell, with loss of stored liquid

(2) No damage tank

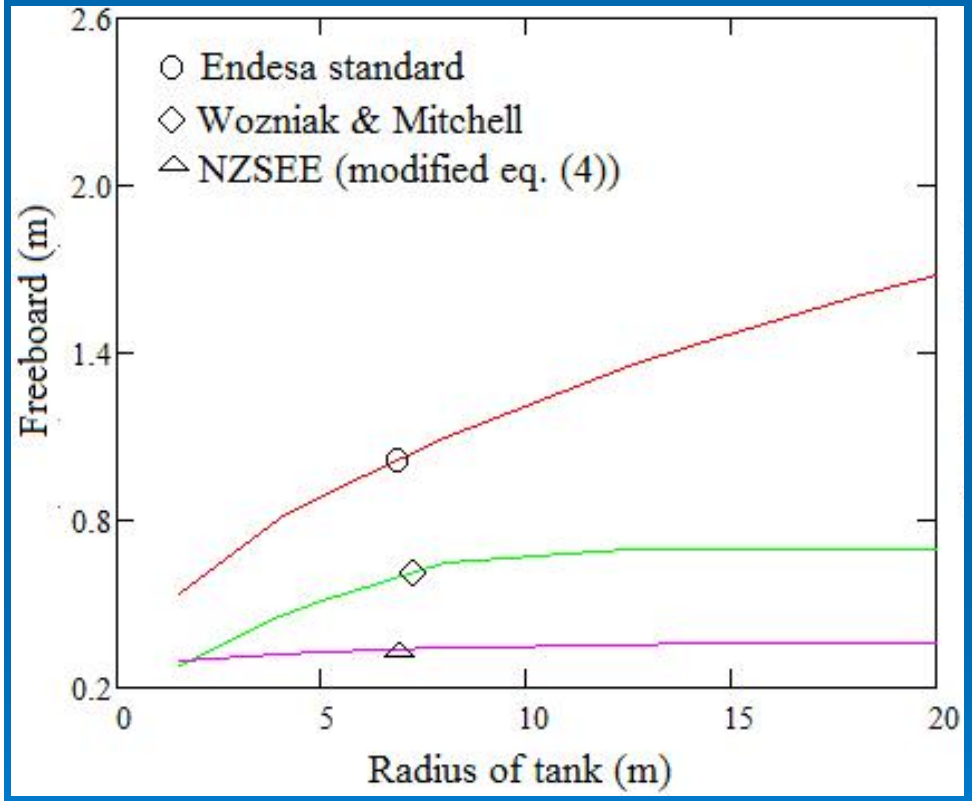
(3) Slight deformation

COMMENTS

- All tanks were self-anchored, increment in stress on shell for uplift of wall
- Most of self-anchoring tanks failed were designed according to API 650-E (1980)
- Self-anchored tanks presented primarily fails type BS and HS
- Before 1985 in Chile were not available design codes, was created in 1986
- Incorporate anchor in tanks

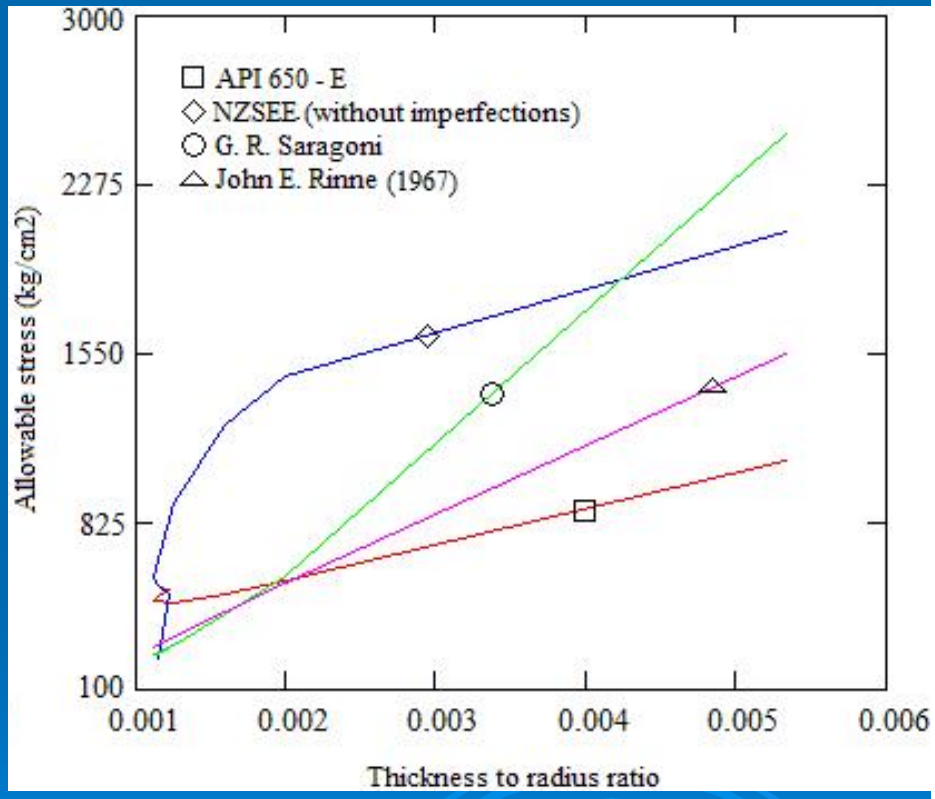
COMPARATIVE ANALYSES

Freeboard



Large Dispersion

Allowable Stress



Imperfections in Shell

CONCLUSIONS

- In 1985 the API Standard did not specify anchored tanks, this was corrected in the 2010 Edition of the code
- Use of mechanical anchoring, has been discussed among Chilean designers for years
- In 2010, no major observed failures, due to tanks being mechanically anchored
- In 1985, repeated failures self- anchored tanks

CONCLUSIONS

- Make necessary to use mechanical anchoring for reduce the risk of collpase
- Mechanical anchoring seems to increase convective stress
- During subduction Chilean earthquakes recorded high vertical seismic components or accelerations
- NCh2369.Of2003:
  - Factors R and ξ for vibrations modes
  - Include anchorage of Tanks

RECOMMENDATIONS

- In Official Chilean Standard NCh2369.Of2003, R_c=4 must be corrected for R_c=1 (Convective Mode)
- Investigate methods for calculating freeboard with reasonable values due to large dispersion
- Must consider imperfections in formula for buckling stress
- Instrumentation is strongly recommended for tanks

THANKS FOR YOUR ATTENTION