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International Centre for Theoretical Physics**



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**Advanced Conference on Seismic Risk Mitigation and Sustainable  
Development**

*10 - 14 May 2010*

**EARTHQUAKE ENGINEERING LESSONS FROM STRONG EARTHQUAKES  
RELATED TO ADVANCED WAYS FOR SEISMIC RISK MITIGATIONS**

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*Universidad de Chile  
Santiago  
Chile*



# EARTHQUAKE ENGINEERING LESSONS FROM STRONG EARTHQUAKES RELATED TO ADVANCED WAYS FOR SEISMIC RISK MITIGATIONS

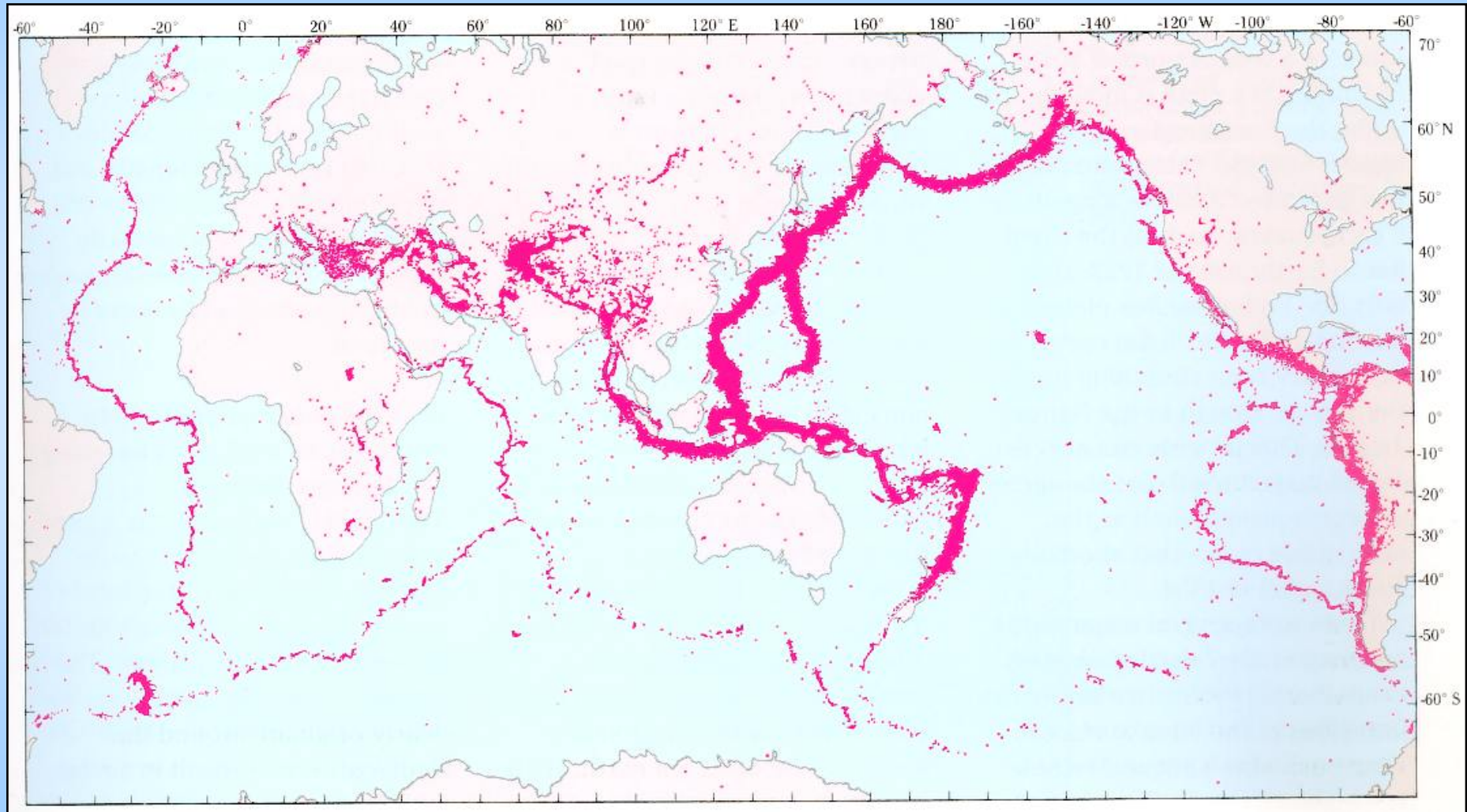
G. Rodolfo Saragoni  
Universidad de Chile



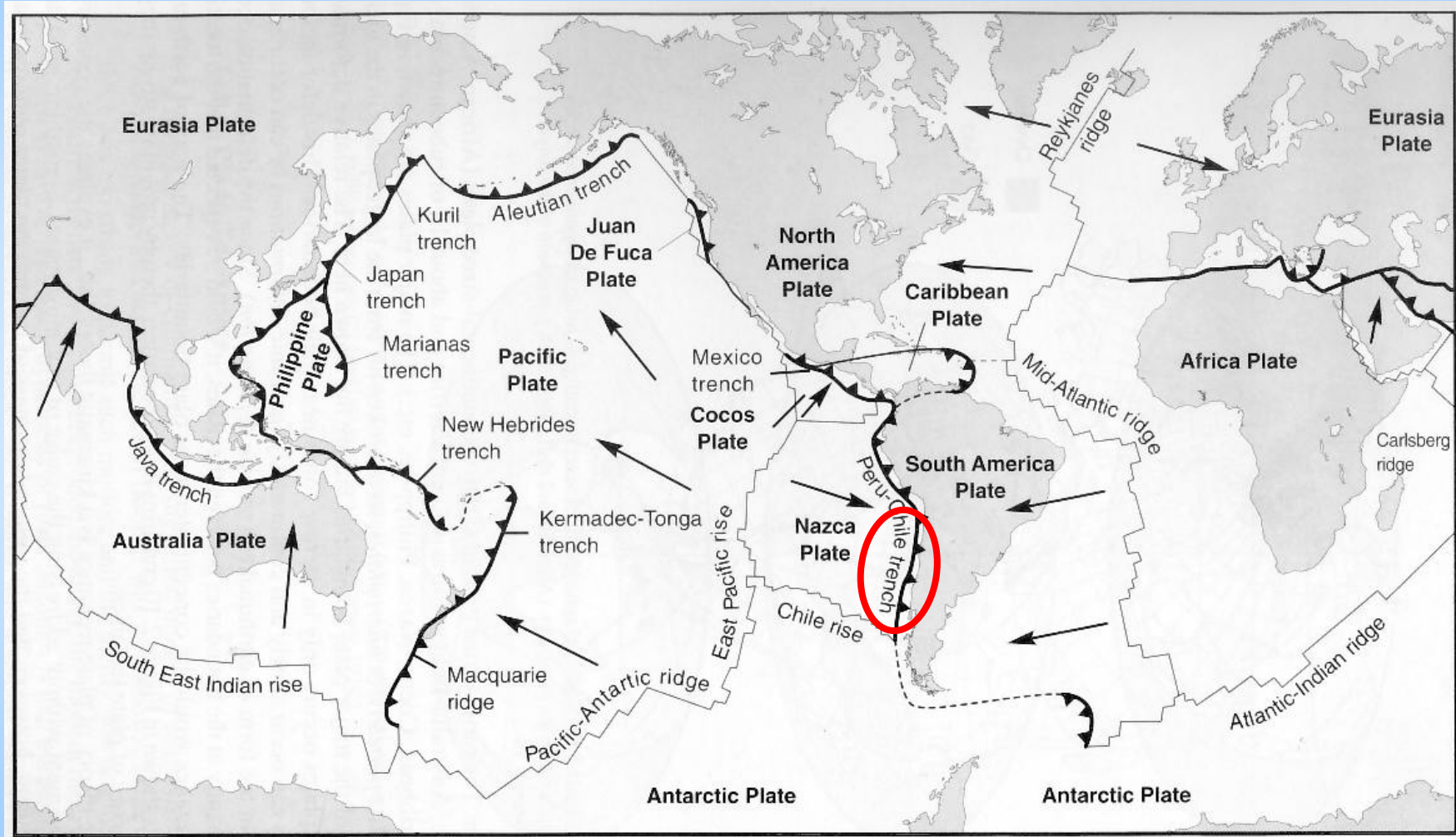
# *THE 2010 CHILE, $M_w=8.8$ EARTHQUAKE*

G. Rodolfo Saragoni  
Universidad de Chile

# CIRCUMPACIFIC SEISMICITY



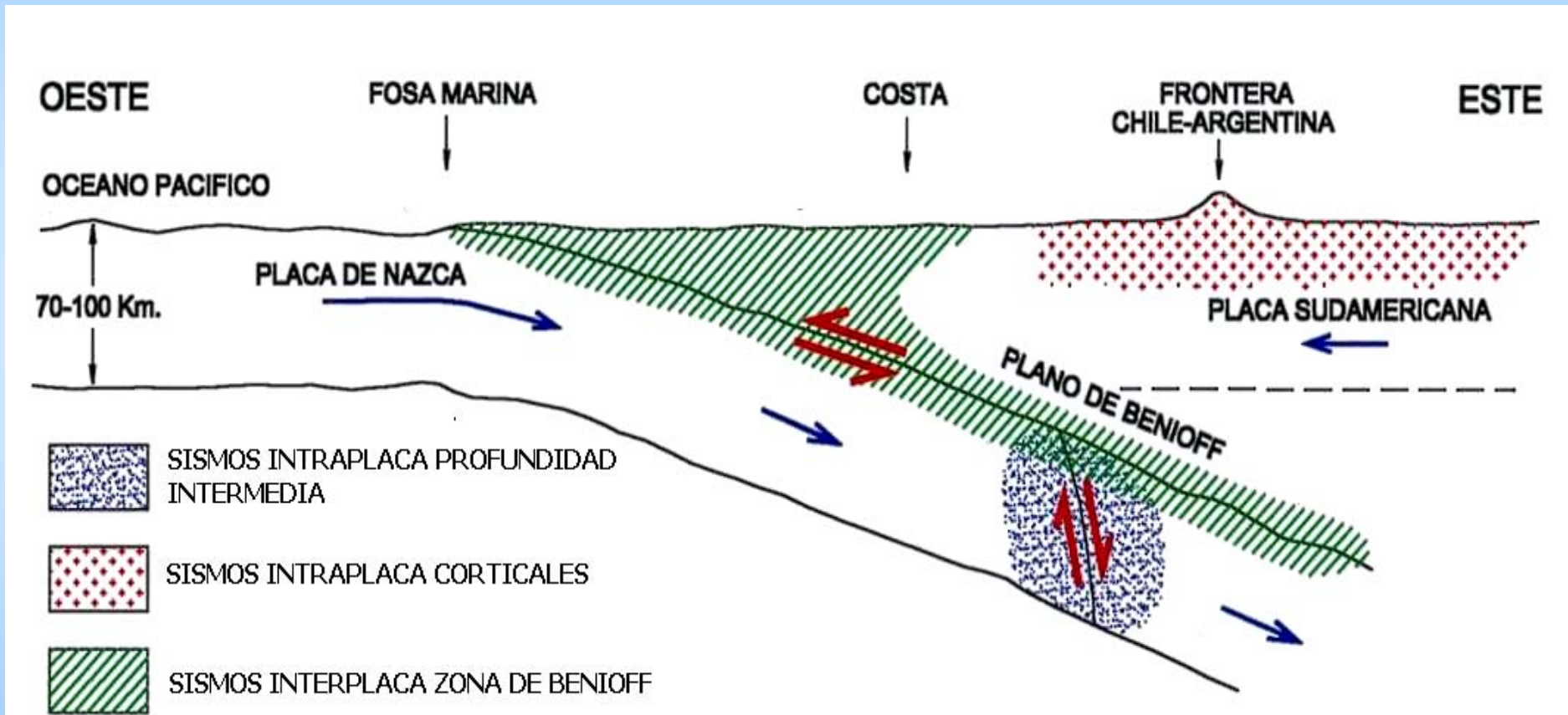
# CIRCUMPACIFIC SUBDUCTION



# SUBDUCTION OF NAZCA PLATE UNDER SOUTH AMERICA PLATE



# SUBDUCTION PLATE INTERACTION

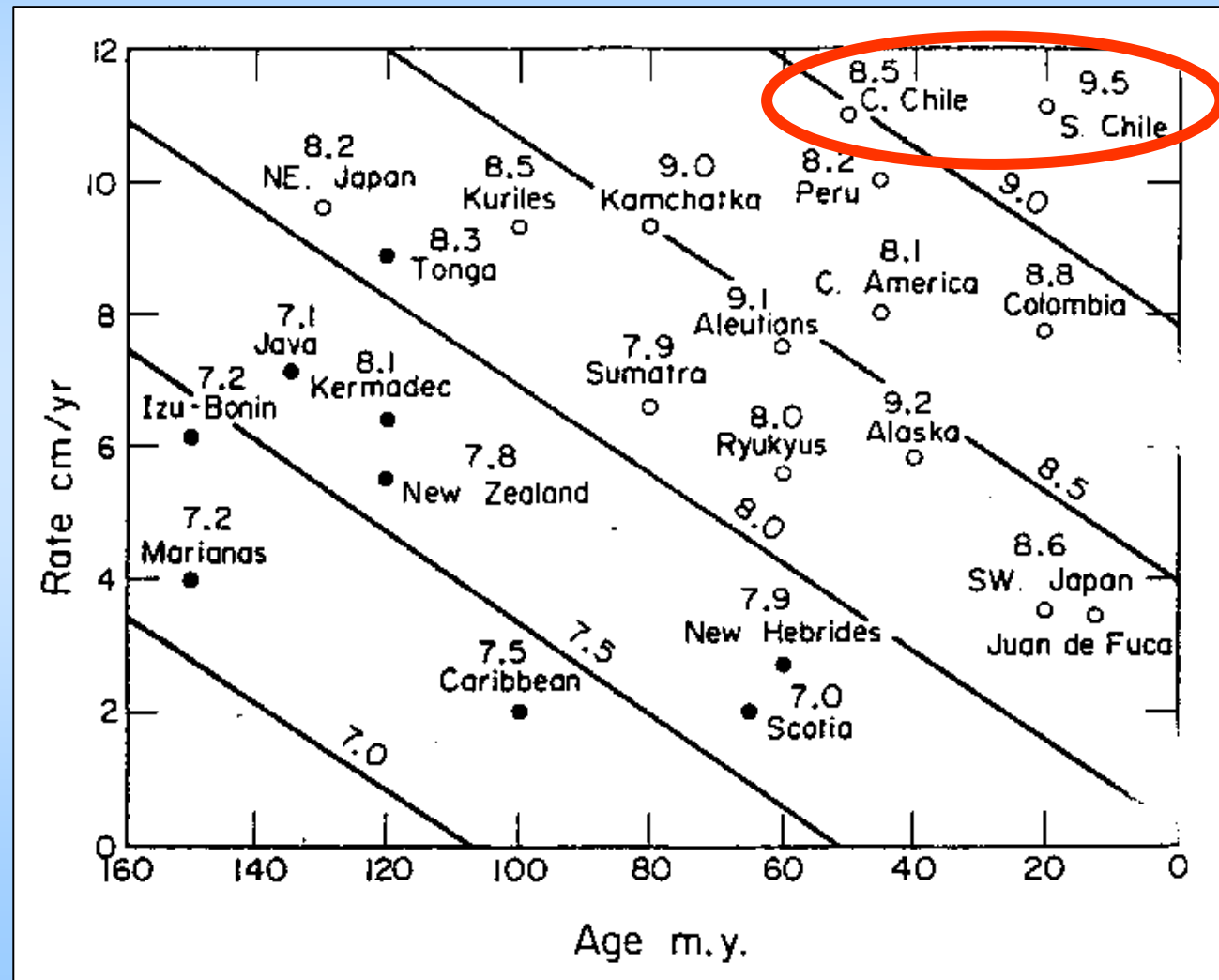


# TYPES OF EARTHQUAKES

- **INTERPLATE THRUST SUBDUCTION EARTHQUAKES (CHILE 2010 EARTHQUAKE)**
- **INTRAPLATE SUBDUCTION EARTHQUAKES**
- **CORTICAL EARTHQUAKES (SUPERFICIAL RELATED WITH FAULTS)**
- **STRIKE SLIP FAULT DUE TO INTERPLATE INTERACTION (MAGALLANES FAGNANO FAULT)**

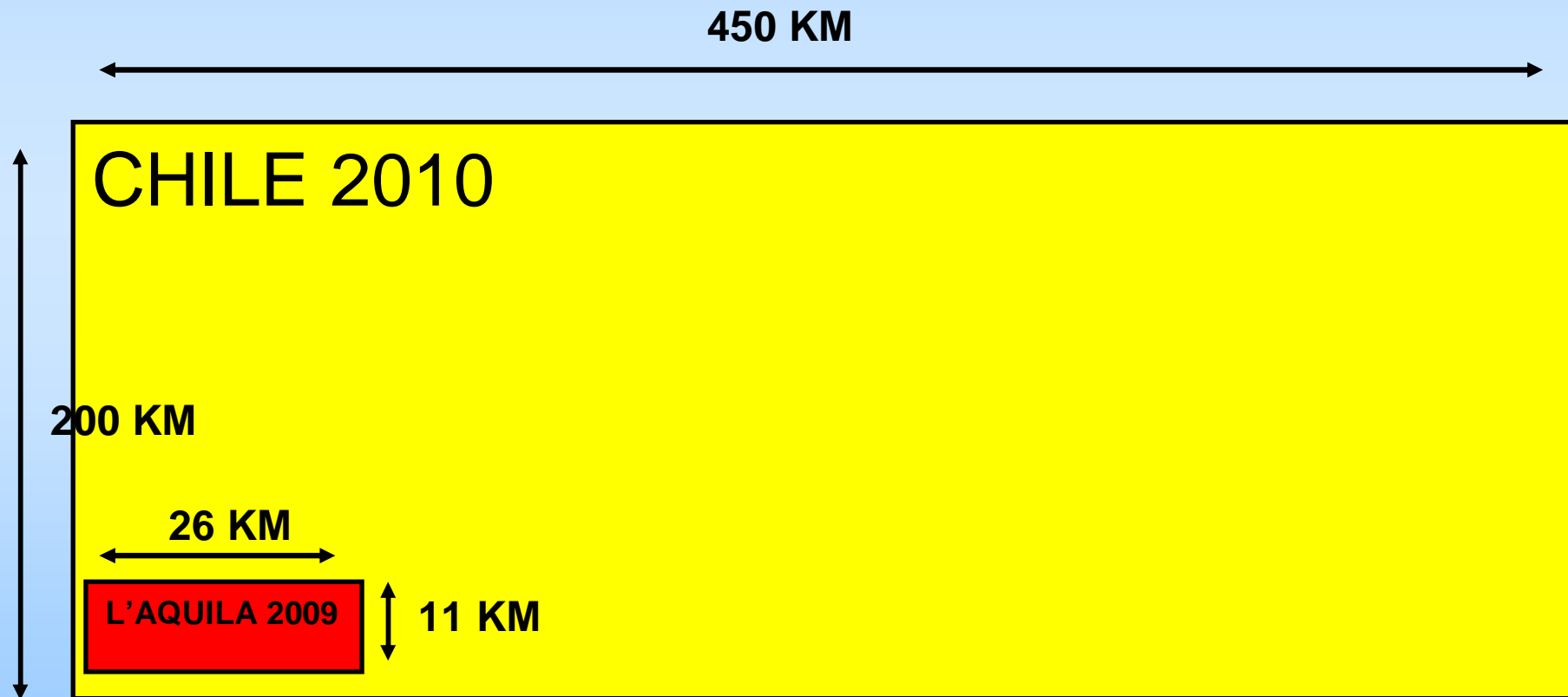


# LARGE SUBDUCTION EARTHQUAKES



$$M_w = -0.089 \cdot T + 0.134 \cdot V + 7.96 \leftarrow \text{TSUNAMIS}$$

# COMPARISON WITH L'AQUILA EARTHQUAKE



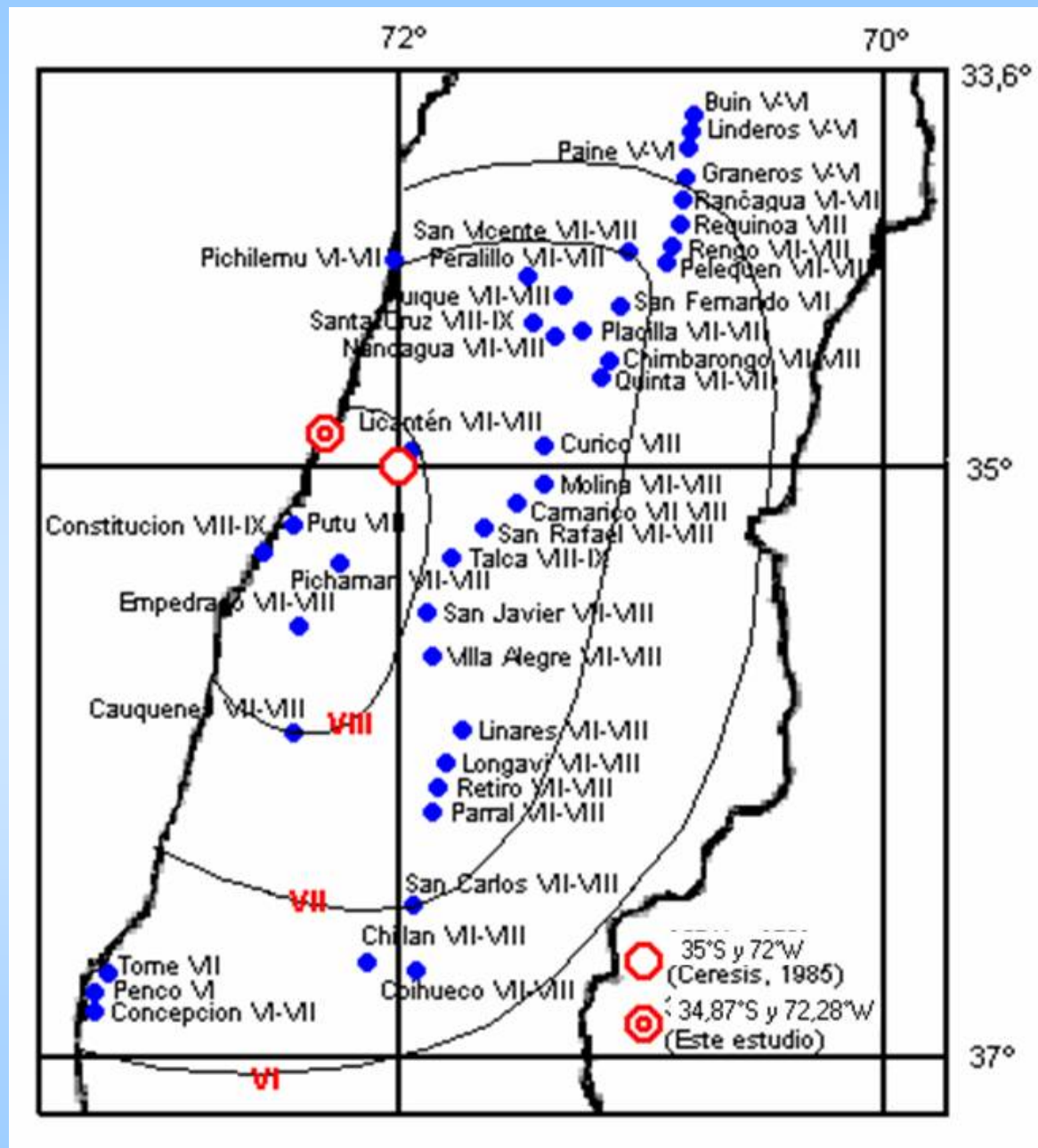
# THE STUDY OF THE EARTHQUAKE IS DIVIDED IN THREE STAGES:

- PRESEISMIC
- COSEISMIC
- POSTSEISMIC

# PRESEISMIC STAGE

# THE SEISMIC GAP SOUTH OF MATANZAS

THE EARTHQUAKE WILL BE  
MAGNITUDE 8.0 – 8.3  
SIMILAR TO  
TALCA EARTHQUAKE OF 1928



**Talca Earthquake 1928 (Sanhueza y Astroza)**



## **THE EARTHQUAKE WOULD BE CHARACTERIZED BY:**

- TO BE THE ONE WHICH MORE AFFECT THE TALL BUILDINGS IN SANTIAGO (CAPITAL OF CHILE)**
- TO PRODUCE THE COLLAPSE OF MOST OF ADOBE STRUCTURES IN COLCHAGUA PROVINCE**
- A MODERATE TSUNAMI**
- A 500 Km RUPTURE**

**STUDY OF PISCO EARTHQUAKE,  
PERU 2007, Mw=7.9**

**EFFECTS ON HIGHRISE BUILDINGS**

# **EFFECTS ON HIGHRISE BUILDINGS**

Miraflores Building 17 Story, Lima







# **EFFECT OF NEW TALCA EARTHQUAKE IN SANTIAGO**

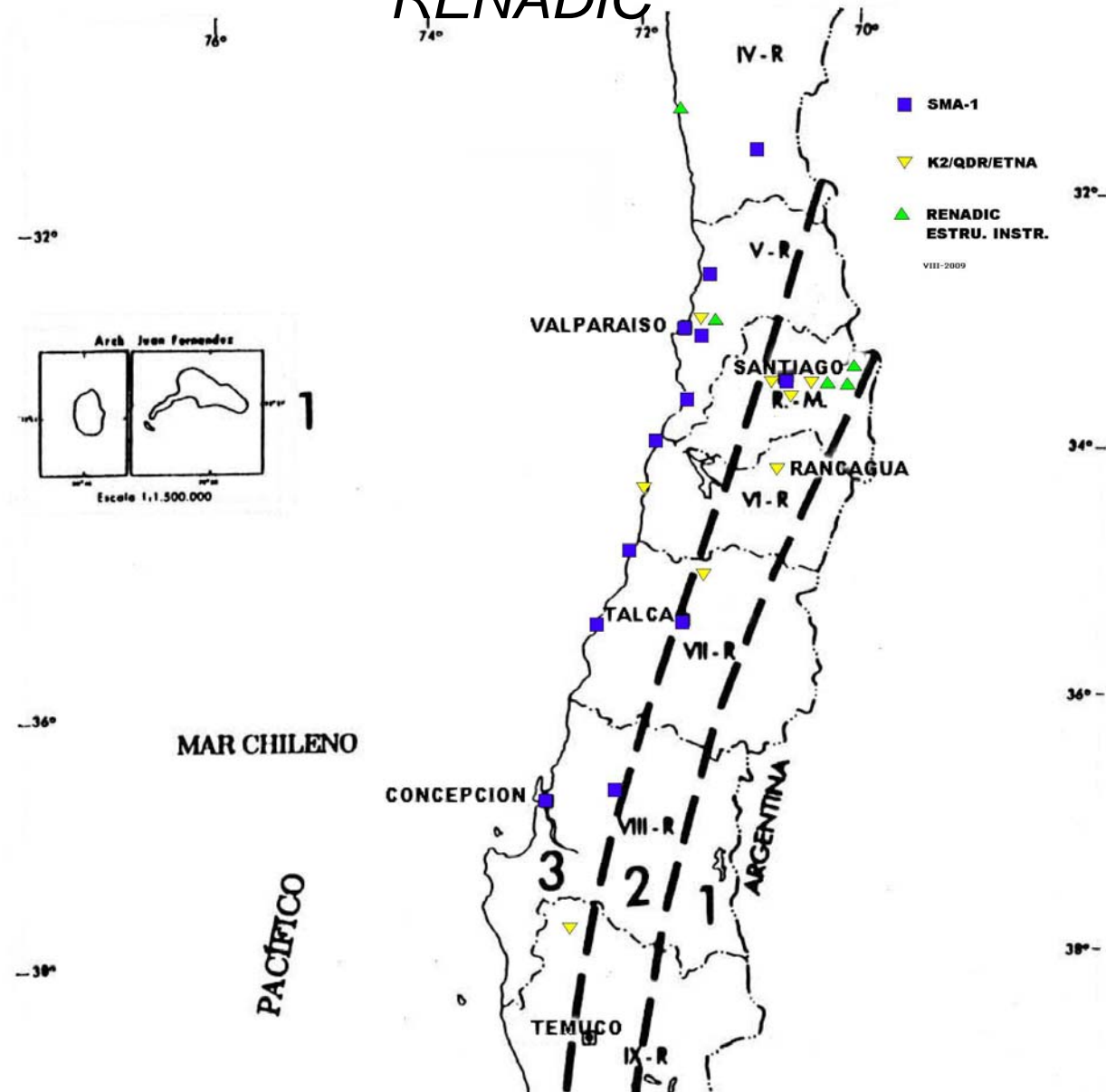
## **PERFORMANCE DESIGN**

# ACELEROGRAFIC INSTRUMENTATION



# INSTRUMENTATION U. DE CHILE RENADIC

NCh433



# COSEISMIC STAGE

# CHARACTERISTICS OF M<sub>w</sub> =8.8 EARTHQUAKE

**Epicenter Cobquecura**  
**35.909°S 73.733°W**

**Depth**  
**35Km**

**Deaths 430**

**Losses US 30.000.000.000 (U\$10.000.000.000)**

**Duration 2,5 minutes**

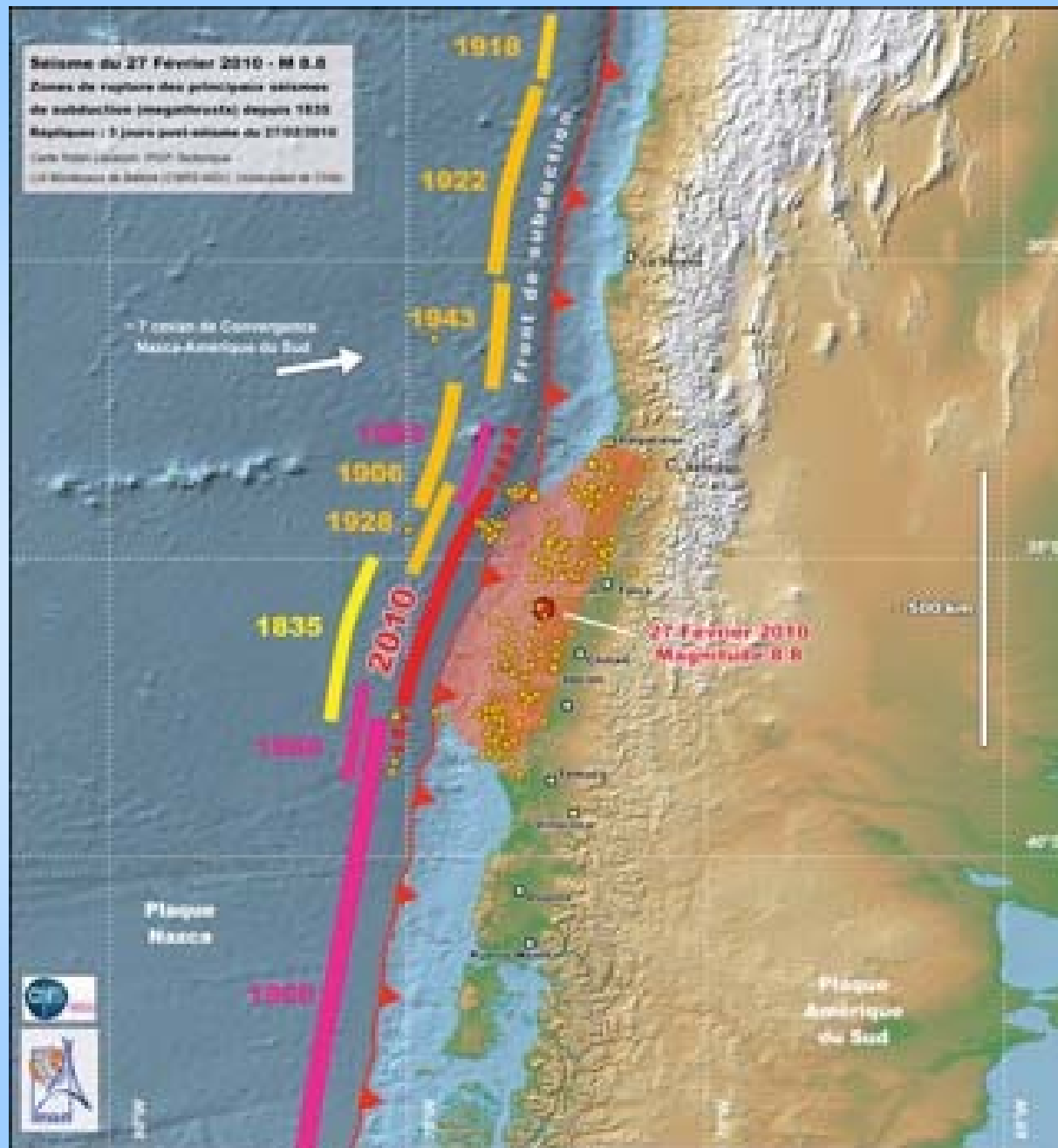
**Maximun Mercalli Intensity IX (Low Constitución)**

**Bilateral Rupture, Dominant to the North**

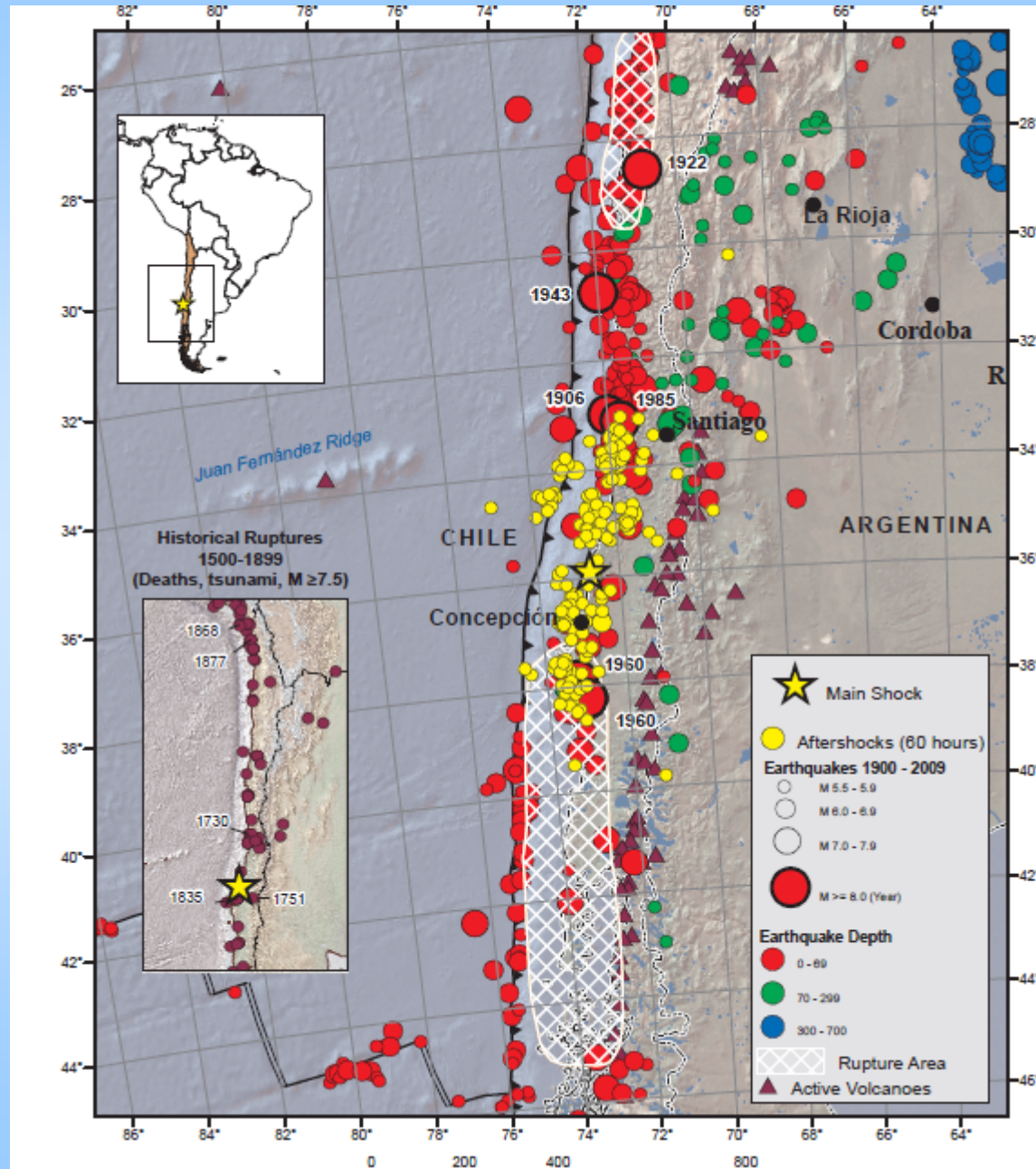
**Important Tsunami**

**Surface faulting was activated**

**Rupture Length Similar to  
Concepcion 1835 Earthquake NO  
to Talca 1928 Earthquake**

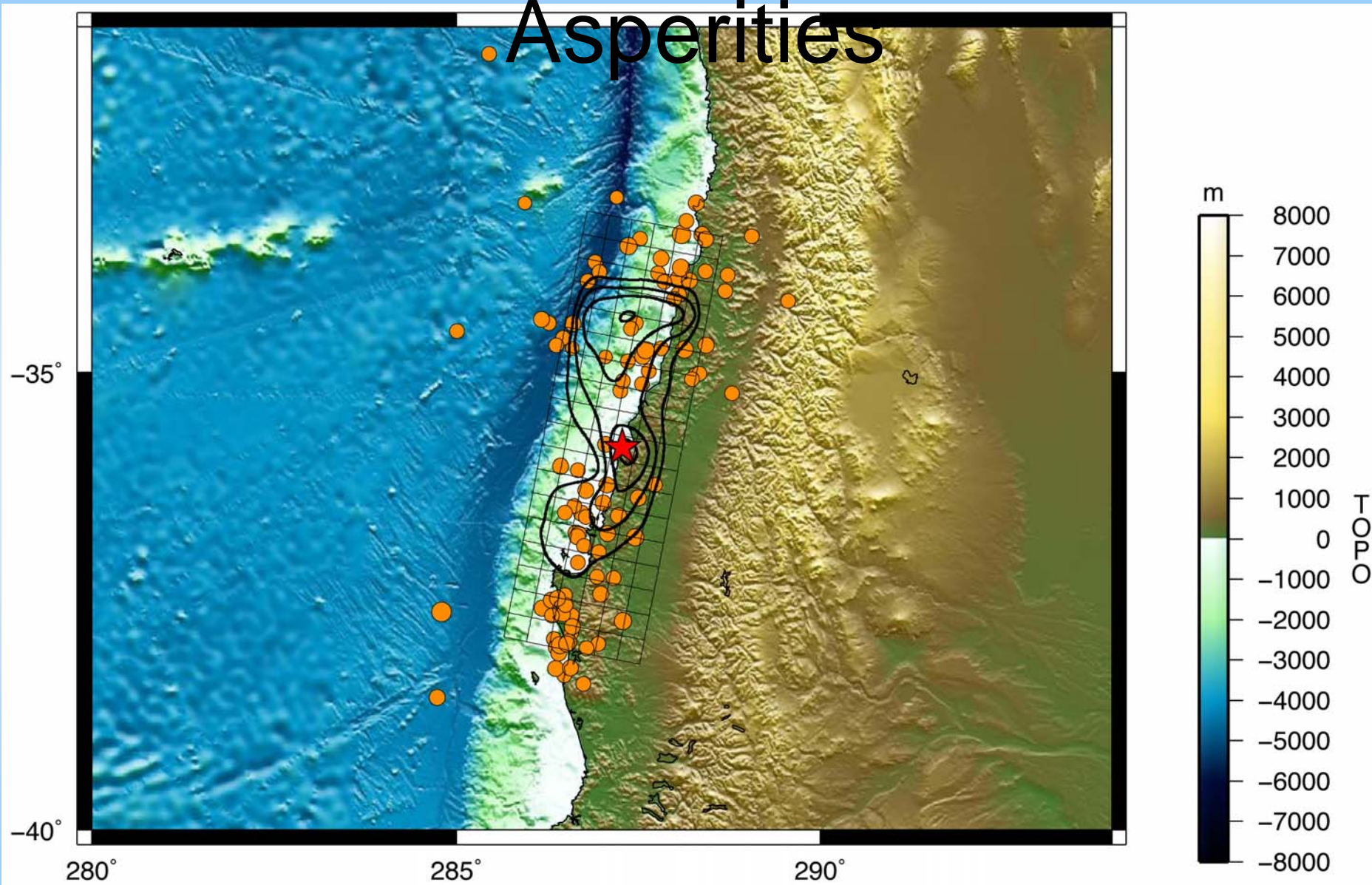


# CHILE 2010 EARTHQUAKE



USGS

# Asperities



REGISTRO RENADIC: ESTACION: VIÑA DEL MAR - P. SOTO R. BOROSCHEK  
UNIVERSIDAD DE CHILE - RED NACIONAL DE ACELEROGRAFOS  
( Frec. Banda: 0.033 - 45 Hz)

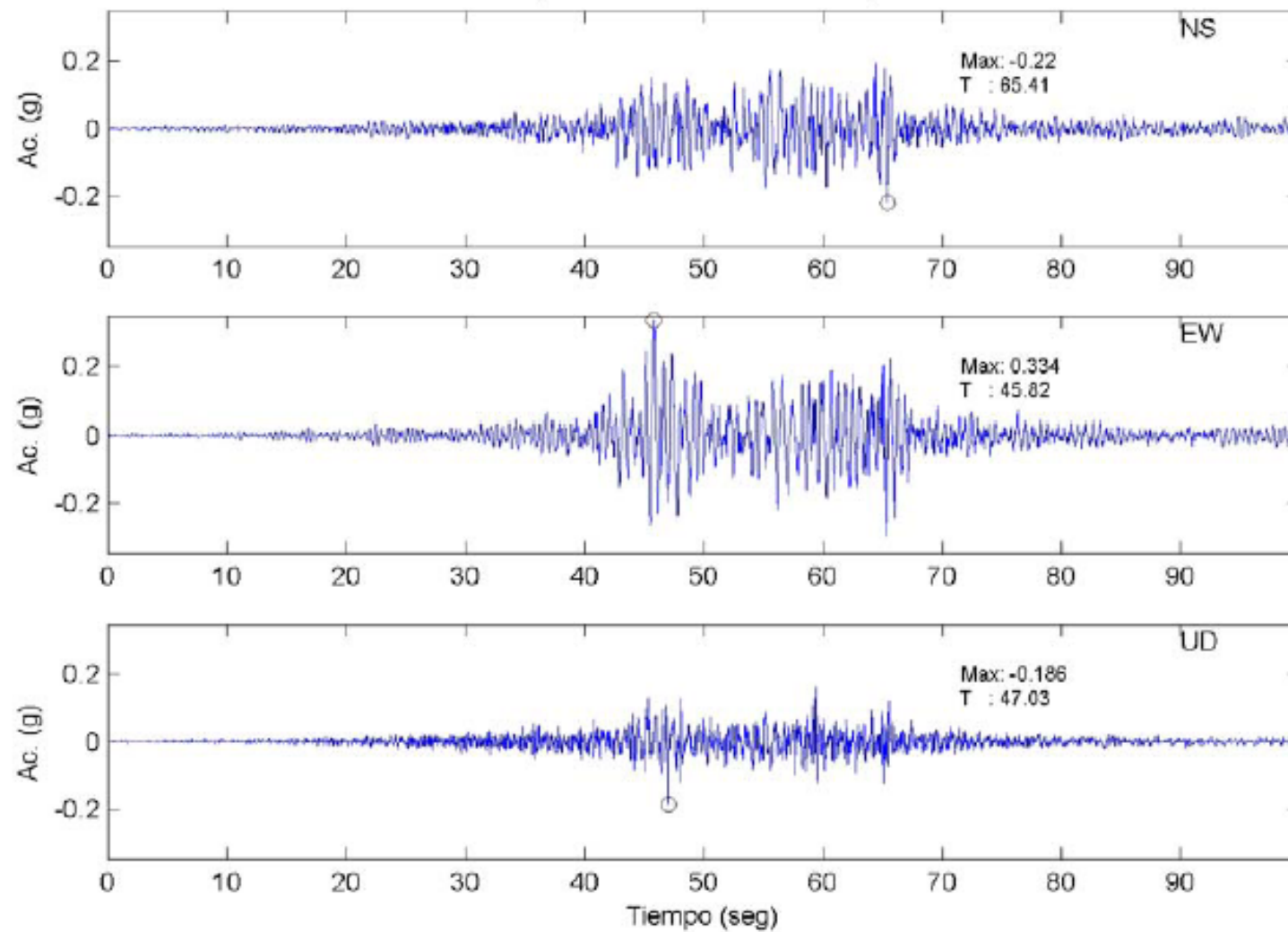
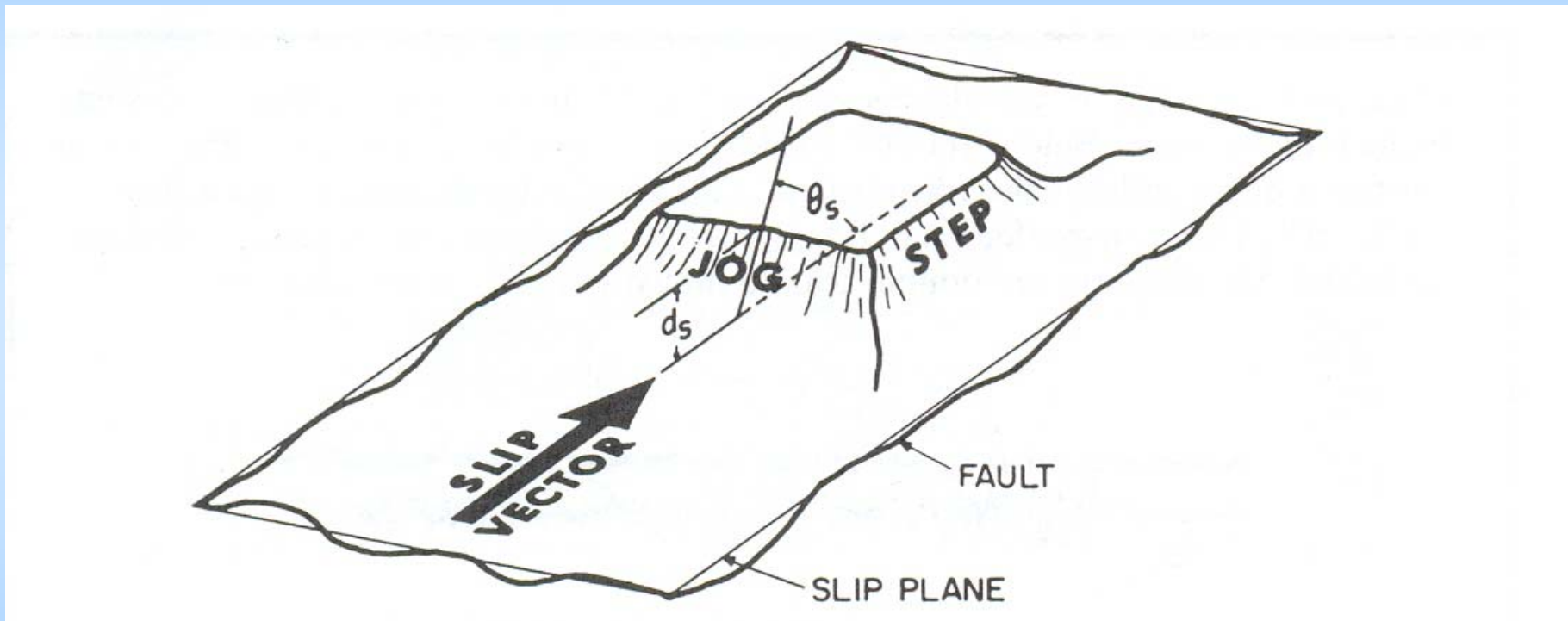


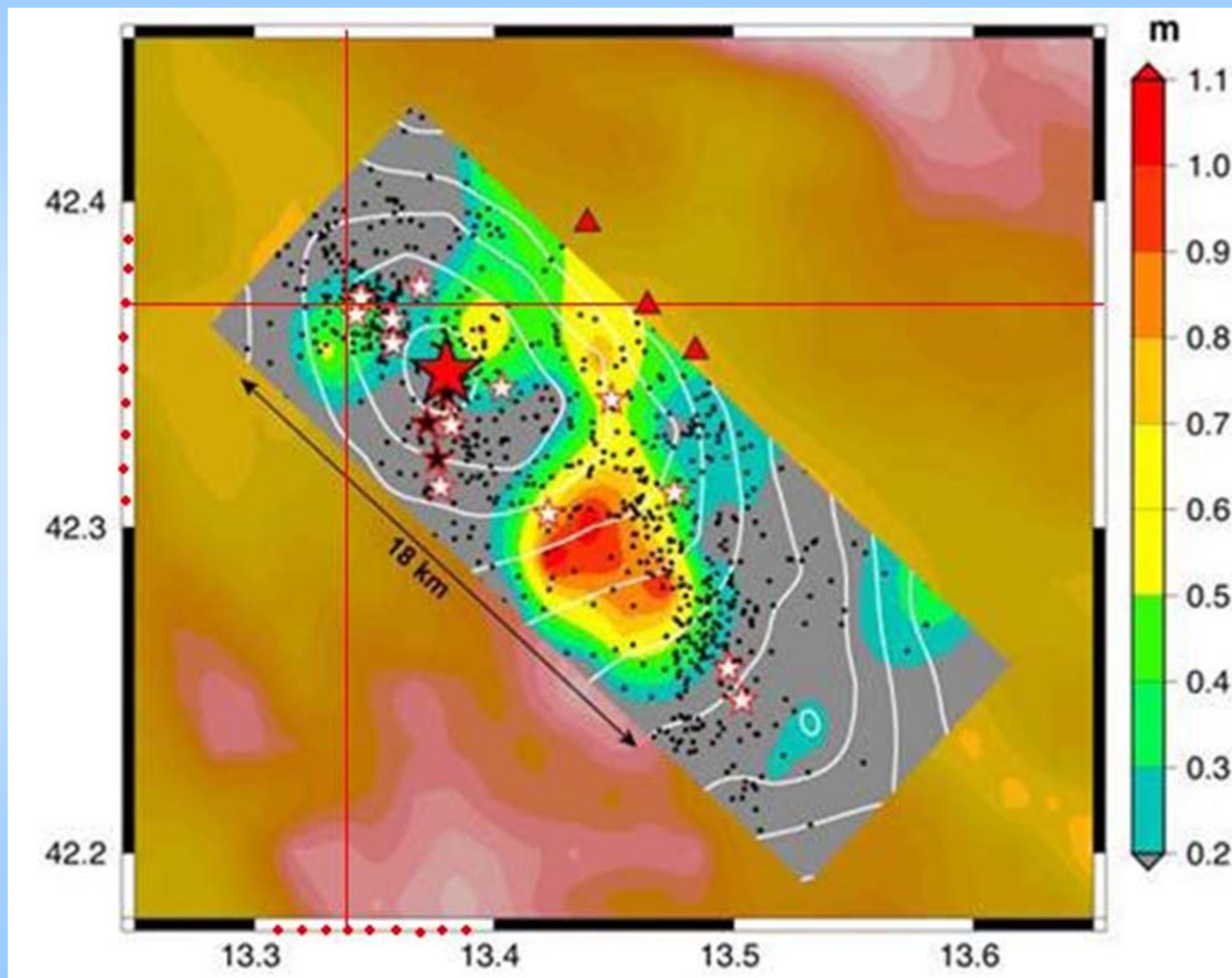
Figura 22 Registro de Aceleraciones Estación Viña del Mar.



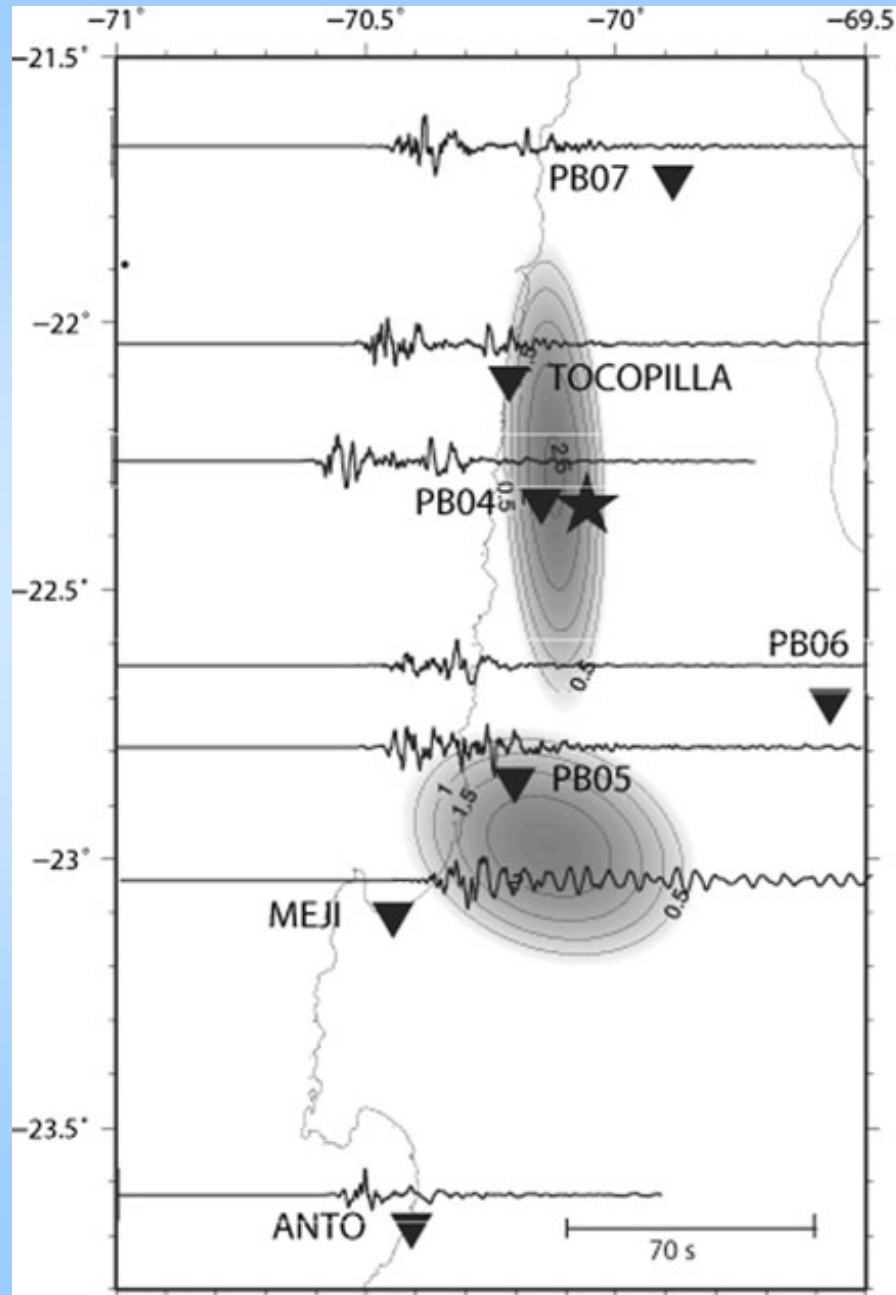
## Asperity cartoon (Sholz, 1990)



# L'AQUILA 2009 $M_w=6.3$



# TOCOPILLA 2007, M=7.7



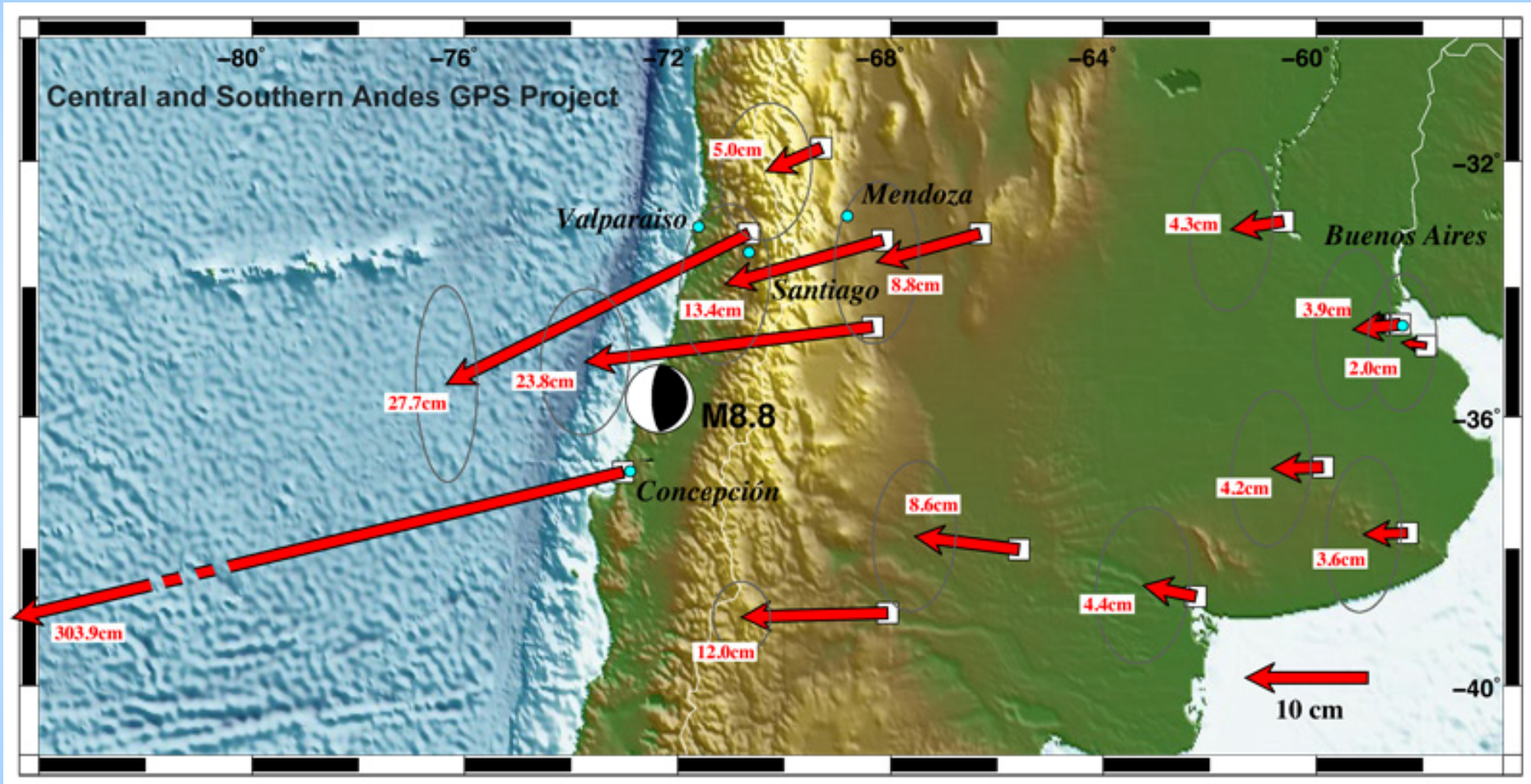
Pure Appl. Geophys.  
© 2010 Birkhäuser / Springer Basel AG  
DOI 10.1007/s00024-010-0117-x

Pure and Applied Geophysics

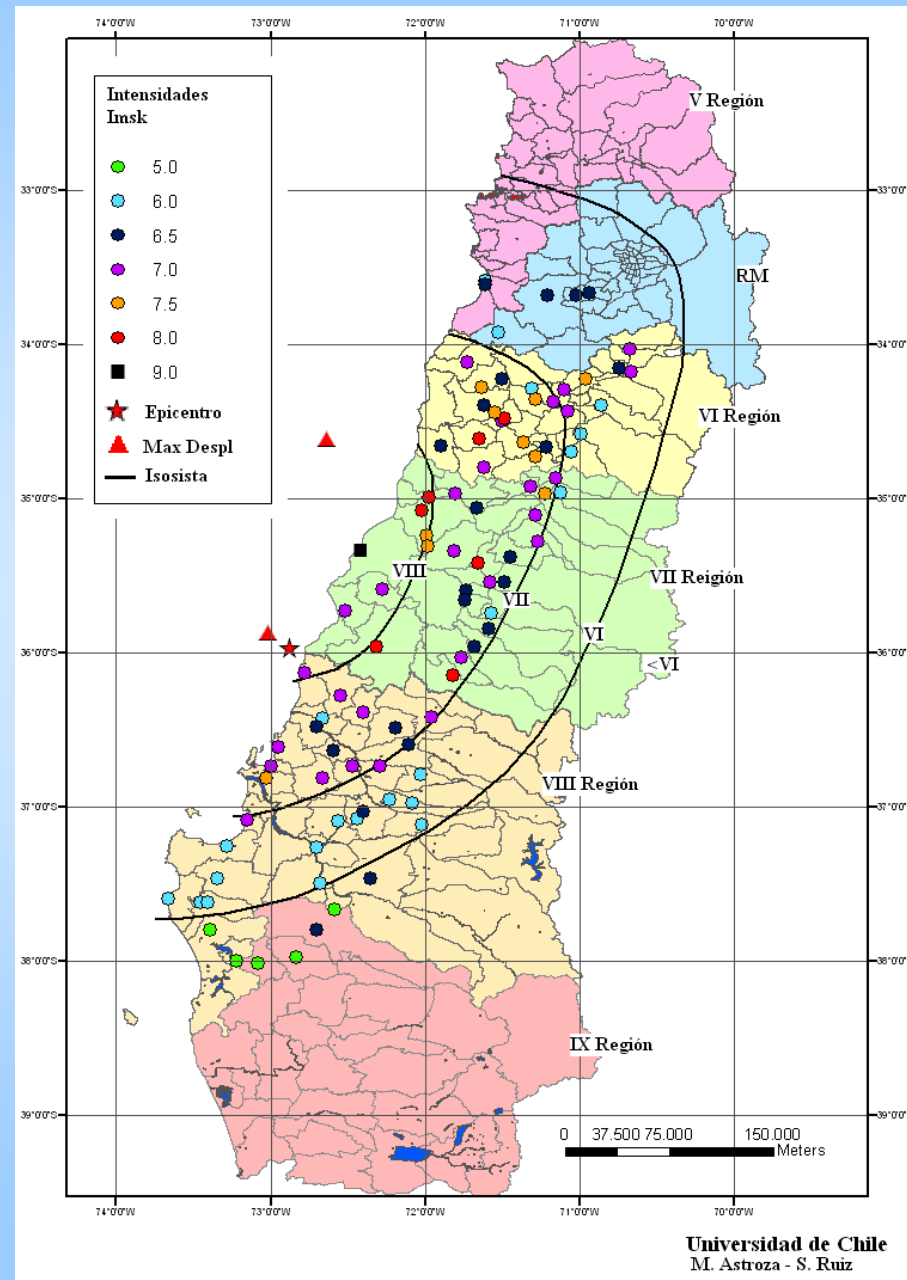
Identification of High Frequency Pulses from Earthquake Asperities Along Chilean Subduction Zone Using Strong Motion

S. RUIZ,<sup>1,2</sup> E. KAUSEL,<sup>1</sup> J. CAMPOS,<sup>1</sup> G. R. SARAGONI,<sup>1</sup> and R. MADARIAGA<sup>2</sup>

# Coseismic Displacement



# INTENSITIES MSK, CHILE 2010 EARTHQUAKE



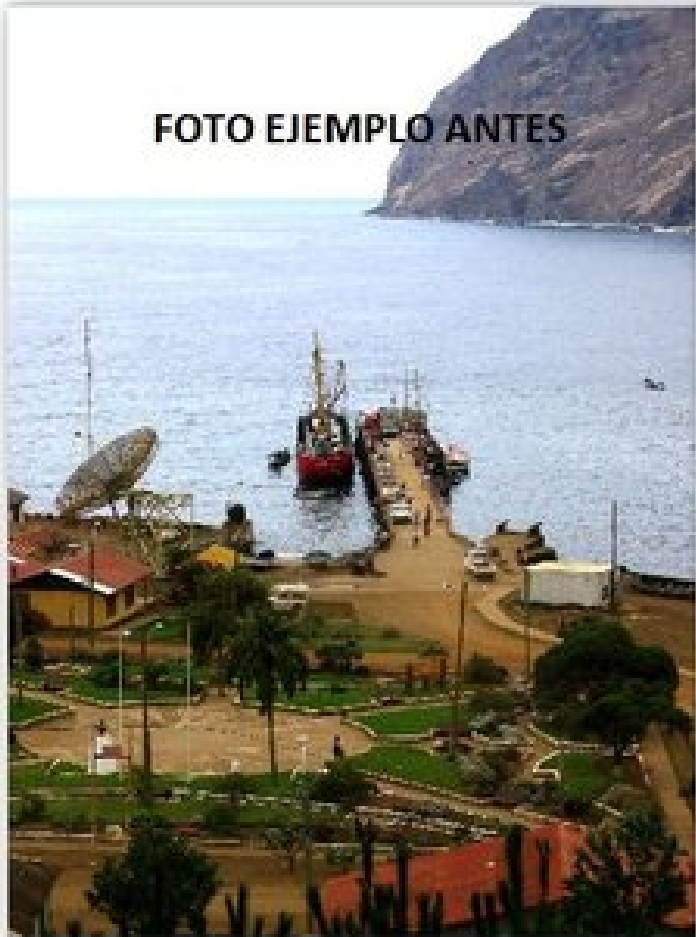
# COLAPSO DEL ADOBE



**TSUNAMI**

# JUAN FERNANDEZ ISLAND

FOTO EJEMPLO ANTES

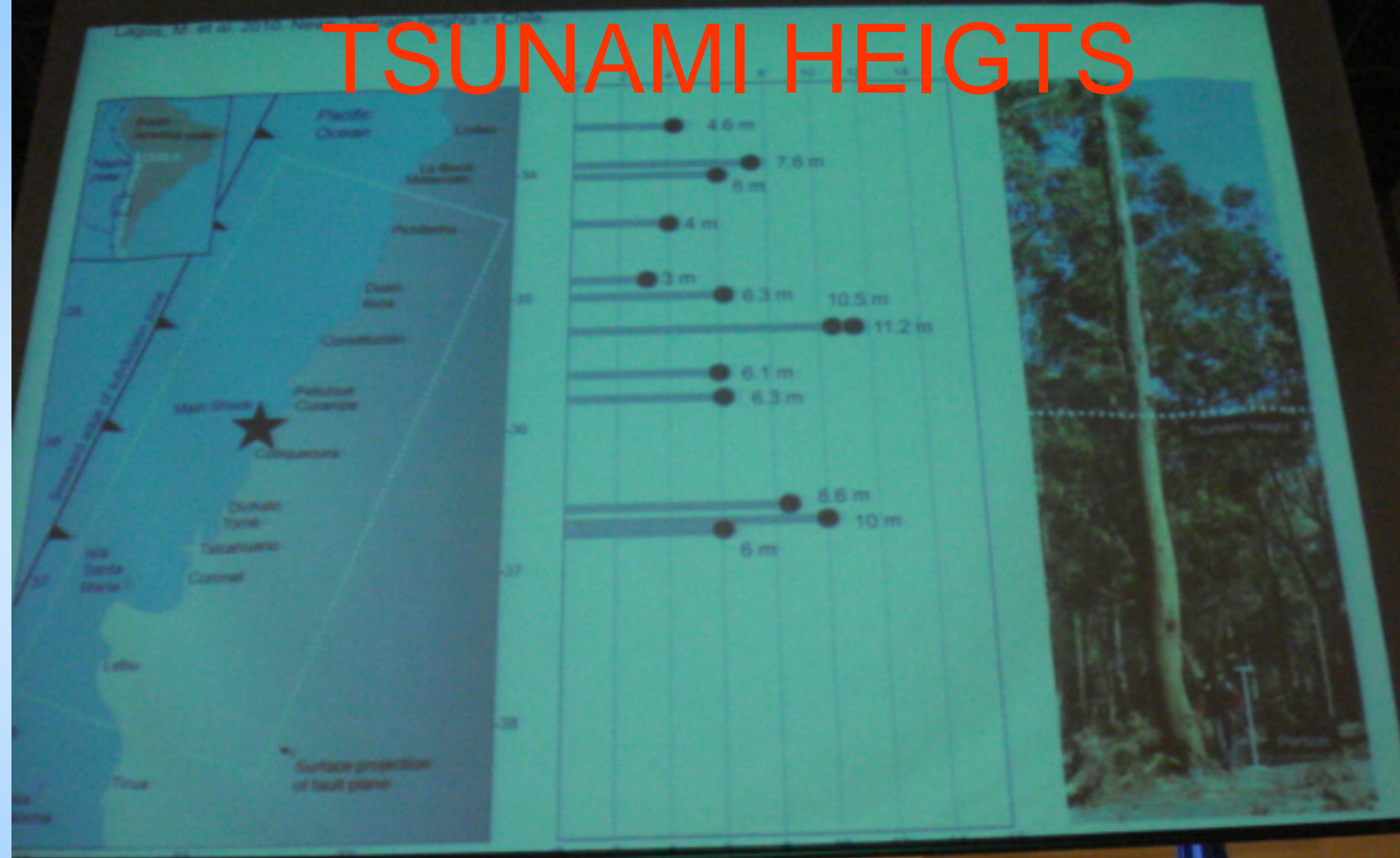




# TALCAHUANO



# TSUNAMI HEIGHTS



# INSTRUMENTATION

# RECORDED ACCELEROGRAMS

- MANY ACCELEROGRAMS RECORDED IN SANTIAGO AT GROUND LEVEL, HIGH RISE BUILDINGS, BRIDGES, ISOLATED BUILDINGS and METRO.
- RECORDED ACCELEROGRAMS AT GROUND LEVEL IN THE MOST DAMAGE CITIES

# RECORDED ACCELEROGRAMS

REGISTRO RENADIC: ESTACION: CRS MAIPU SANTIAGO / P. SOTO R. BOROSCHEK  
UNIVERSIDAD DE CHILE RED NACIONAL DE ACELEROGRAFOS  
( Frec. Banda: 0.06 - 40 Hz)

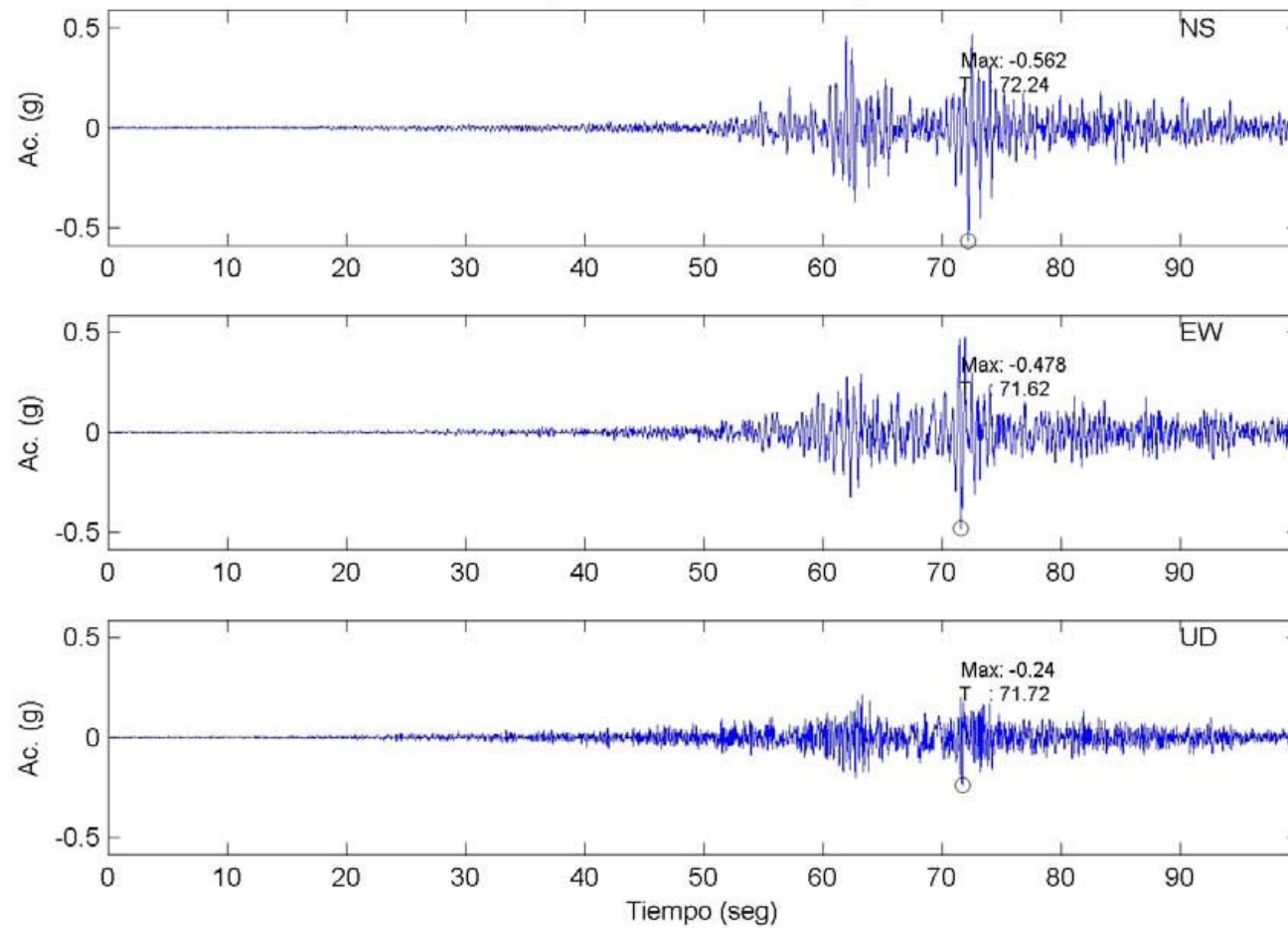




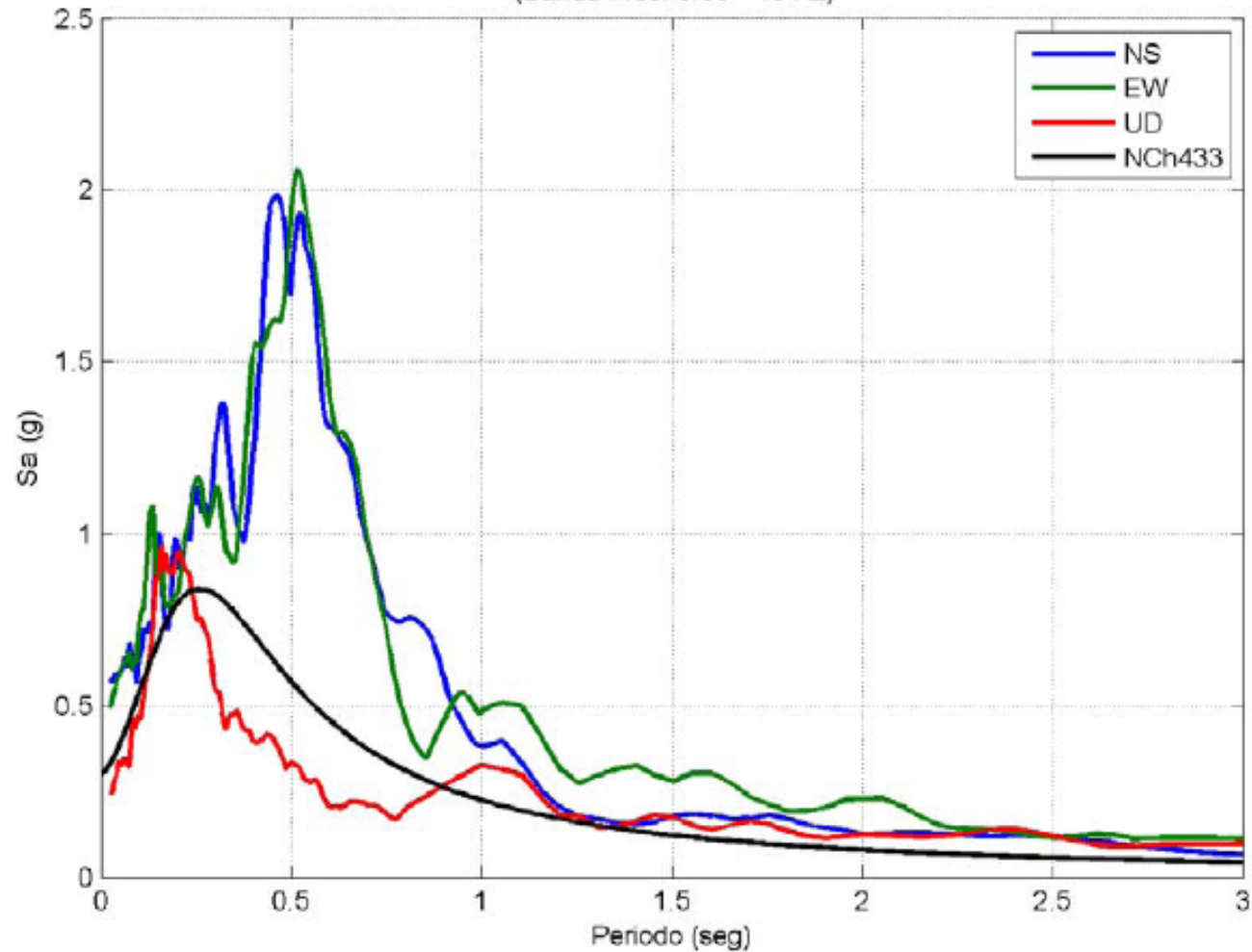
Tabla 1. VALORES EXTREMOS (sin corregir)

Estación	Aceleración Máxima Horizontal (g)	Aceleración Máxima Vertical (g)	OBSERVACION
Universidad de Chile Depto Ing. Civil (Interior Edificio) Santiago	0.17	0.14	
Estación Metro Mirador Santiago	0.24	0.13	
CRS MAIPU RM	0.56	0.24	QDR. Clasificación Suelo Pendiente. Interacción Instrumento-Estructura poco probable. Pendiente Suelo- Estructura
Hosp. Tisne RM	0.30	0.28	QDR. Clasificación Suelo Pendiente
Hosp. Sotero de Río RM	0.27	0.13	QDR. Clasificación Suelo Pendiente
Hosp. Curico	0.47	0.20	QDR
Hosp. Valdivia	0.14	0.05	QDR
Viña del Mar (Marga Marga)	0.35	0.26	
Viña del Mar (Centro)	0.33	0.19	QDR

## Red Sismológica Nacional

Localidad	Aceleración Máx. Horizontal NS	Aceleración Máx. Horizontal EW	Aceleración Máx. Vertical
Colegio San Pedro, Concepción	0.65 g	0.58 g	0.60 g
Cerro Calán, Santiago	0.20 g	0.23 g	0.11 g
Campus Antumapu, Santiago	0.23 g	0.27 g	0.17 g
Cerro El Roble	0.19 g	0.13 g	0.11 g

ESPECTRO de RESPUESTA  $\beta = 5\%$   
REGISTRO: RENADIC: ESTACION: CRS MAIPU SANTIAGO / P. SOTO R. BOROSCHEK  
UNIVERSIDAD DE CHILE RED NACIONAL DE ACELEROGRAFOS  
(Banda Frec: 0.06 - 40 Hz)



**Figura 9 Comparación Espectro de Diseño Norma Chilena NCh433 – Estación CRS MAIPU RM. (Ver Nota General)**



# DAMAGE TO BUILDINGS

- THREE BUILDINGS COLLAPSED:  
ONE IN CONCEPCION  
TWO IN SANTIAGO

# Alto Río - Concepción



# DAMAGE TO BUILDINGS



# DAMAGE TO BUILDINGS



# DAMAGE TO BUILDINGS



# DAMAGE TO BUILDINGS

- MOST BUILDINGS DESIGNED ACCORDING TO SEISMIC CHILEAN CODE Nch 433 “SEISMIC DESIGN OF BUILDINGS” PERFORMED WELL WITHOUT COLLAPSE

# DAMAGE TO BUILDINGS

- THERE ARE SOME HIGH RISE BUILDINGS WITH STRUCTURAL DAMAGE

# CHARACTERISTICS OF THE FAILURE OF THE HIGHRISE BUILDINGS



# HORIZONTAL FAILURE STRIPE IN BASEMENT WALLS

# HORIZONTAL FAILURE STRIPE IN BASEMENT WALLS



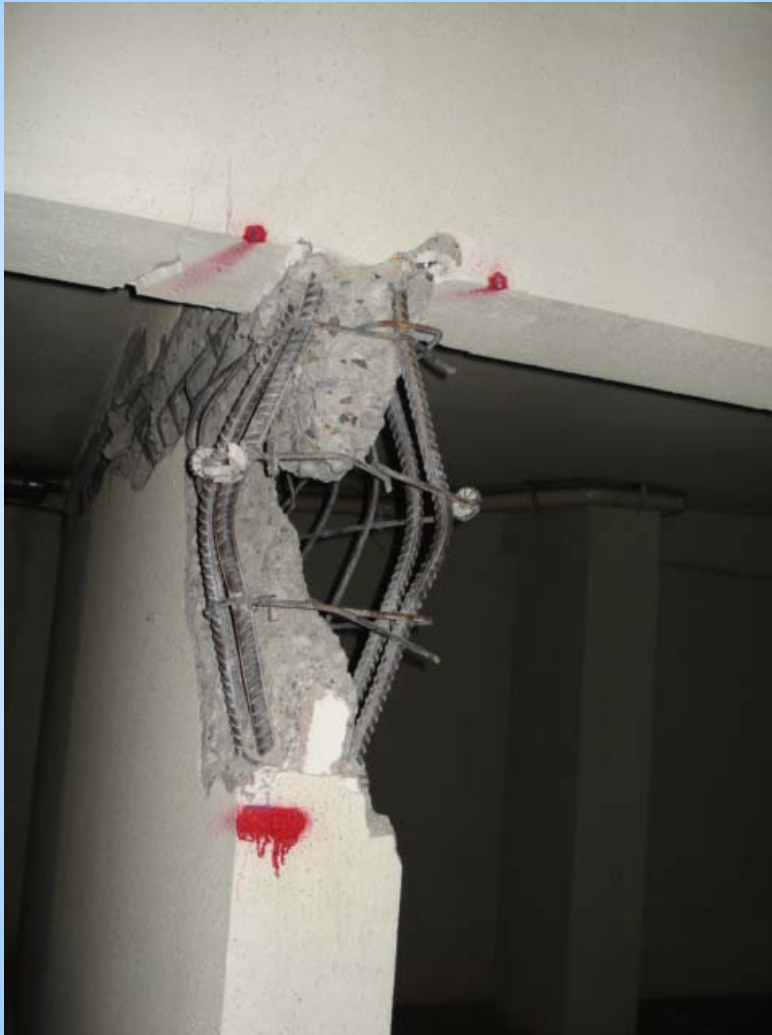
# HORIZONTAL FAILURE STRIPE IN BASEMENT WALLS



# HORIZONTAL FAILURE STRIPE IN BASEMENT WALLS



# HEAD OF THE WALL IN THE ZONE OF HORIZONTAL FAILURE STRIPE



# HEAD OF THE WALL IN THE ZONE OF HORIZONTAL FAILURE STRIPE



# HEAD OF THE WALL IN THE ZONE OF HORIZONTAL FAILURE STRIPE

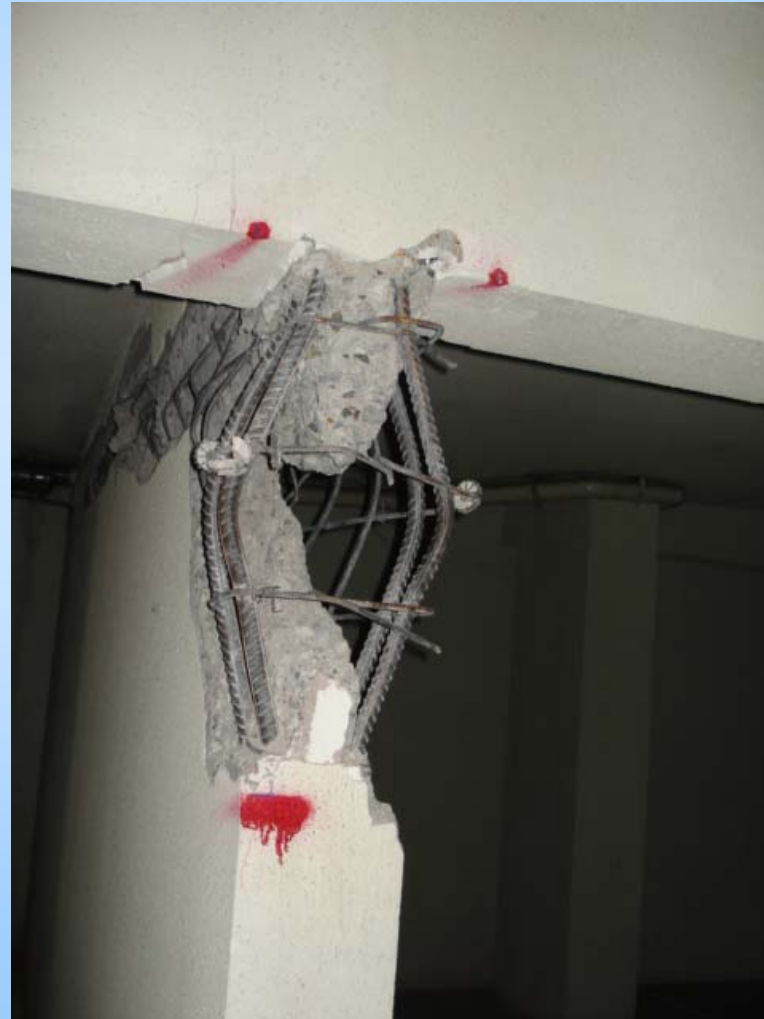


**CABEZAL DE MURO FALLADO INCEPIENTEMENTE:  
CON FALLA HORIZONTAL INCIPIENTE, MOSTRANDO GRIETA  
HORIZONTAL ,DESCASCARAMIENTO EN EL CABEZAL Y PANDEO  
DE BARRAS VERTICALES (EDIFICIO DECLARADO INHABITABLE)**





# FAILURE WITHOUT COMPRESSION WITHOUT COVER SPOILING

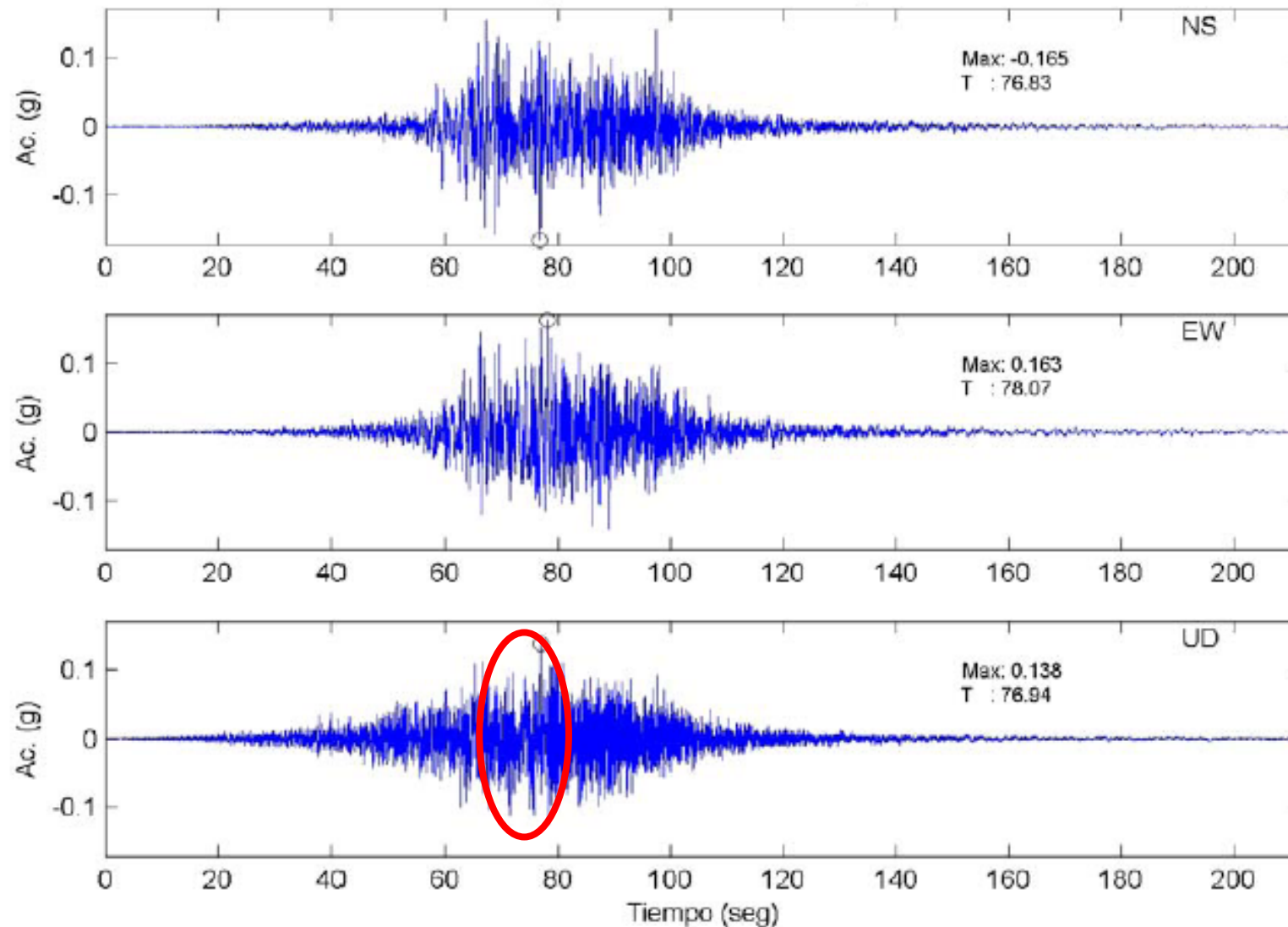


# FAILURE IN UPPER SLABS



**EFFECT OF VERTICAL  
ACCELEROGRAMS PULSE ON  
WALL FAILURE**

REGISTRO RENADIC: ESTACION: UdeCH LEE PROCESA P. SOTO R. BOROSCHEK  
UNIVERSIDAD DE CHILE RED NACIONAL DE ACELEROGRAFOS  
( Frec. Banda: 0.15 - 40 Hz)

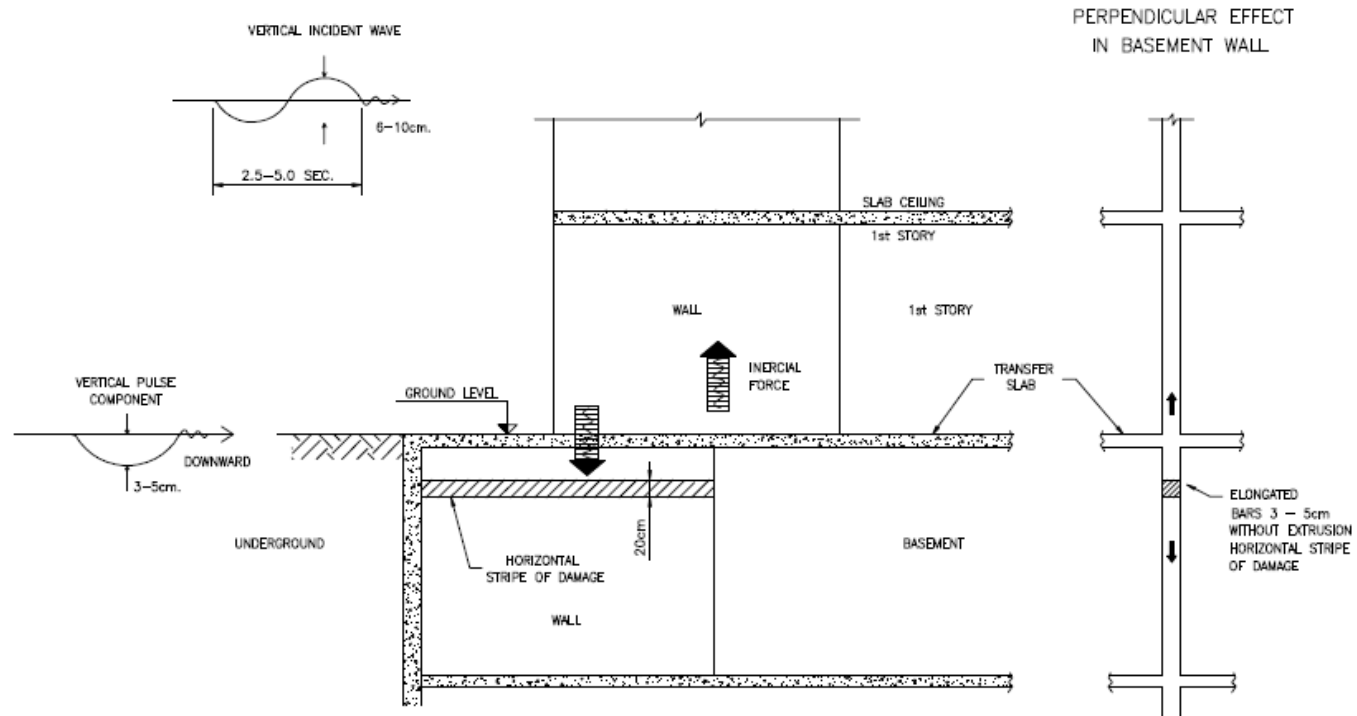


PRESENTATION : RODOLFO SARAGONI H.  
UNIVERSIDAD DE CHILE

SHEAR WALL FAILURE  
OF TALL BUILDINGS  
BY SEISMIC WAVE PROPAGATION

FIRST STAGE

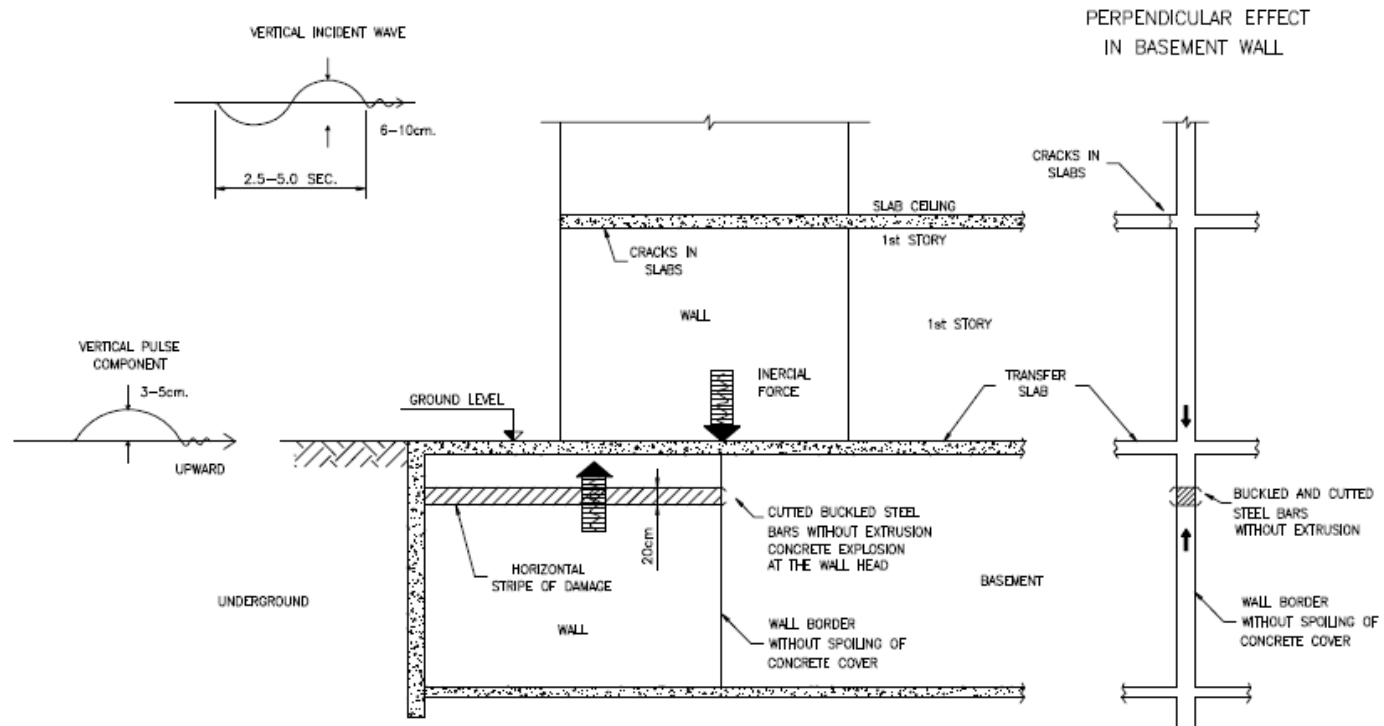
NEGATIVE VERTICAL PULSE (DOWNWARD)  
EFFECT IN THE WALL PLANE OF THE BASEMENT  
ELONGATION OF VERTICAL BARS  
OF 3 TO 5cm. IN THE HORIZONTAL  
STRIPE OF DAMAGE



PRESENTATION : RODOLFO SARAGONI H.  
UNIVERSIDAD DE CHILE

SHEAR WALL FAILURE  
OF TALL BUILDINGS  
BY SEISMIC WAVE PROPAGATION

SECOND STAGE  
POSITIVE VERTICAL PULSE (UPWARD)  
EFFECT ON WALLS AND SLABS



# DAMAGE TO BRIDGES

- MOST OF THE BRIDGES DESIGNED ACCORDING TO CHILEAN CODE FOR BRIDGES PERFORMED WELL









# DAMAGE TO BRIDGES

- FEW BRIDGES DO NOT DESIGN ACCORDING TO CHILEAN CODE COLLAPSE



# SEISMIC PERFORMANCE OF RESEARCH NUCLEAR REACTOR

- CHILE HAS TWO RESEARCH NUCLEAR REACTORS IN SANTIAGO, BOTH PERFORMED WELL DURING THE EARTHQUAKE.
- THE REACTORS ARE:
- LA REINA IN OPERATION
- LO AGUIRRE DISCONTINUED

# RESEARCH NUCLEAR REACTOR LA REINA UNDEAMAGED (PGA = 0.2 – 0.3 g)



# RESEARCH NUCLEAR REACTOR LO AGUIRRE - SANTIAGO UNDAMAGED (PGA = 0.3 g).

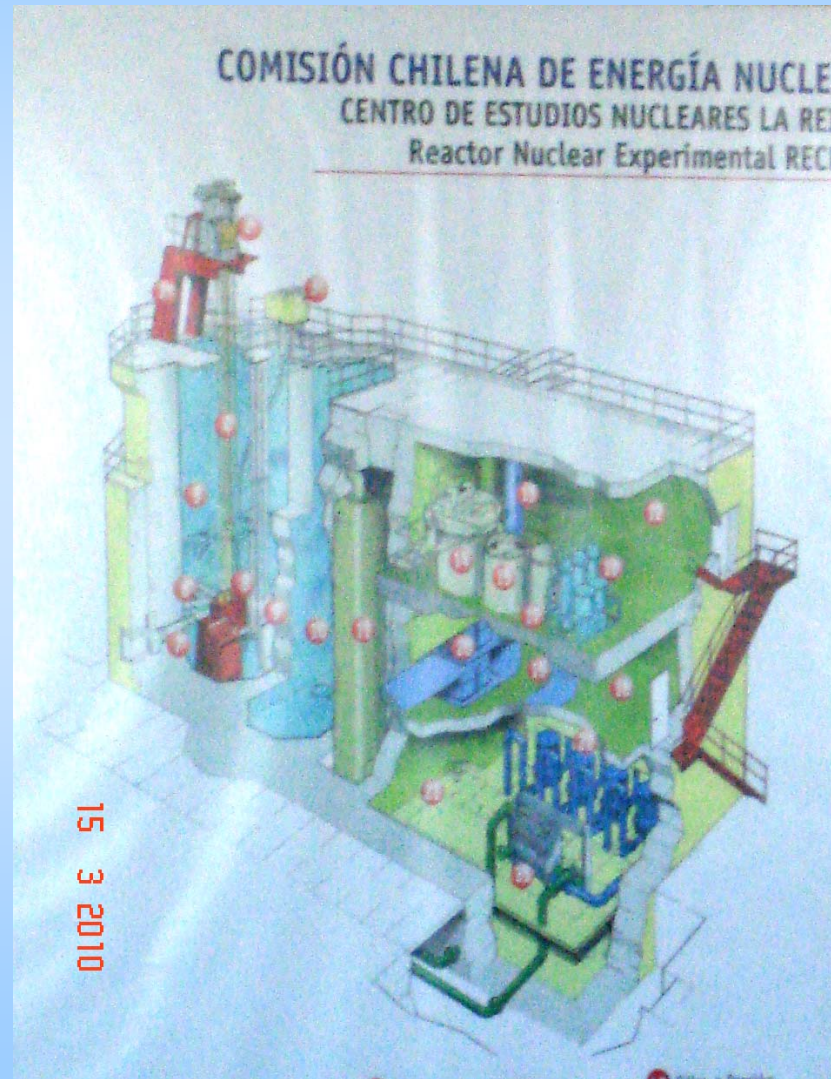


# RESEARCH NUCLEAR REACTOR LA REINA UNDEAMAGED (PGA = 0.2 – 0.3 g)

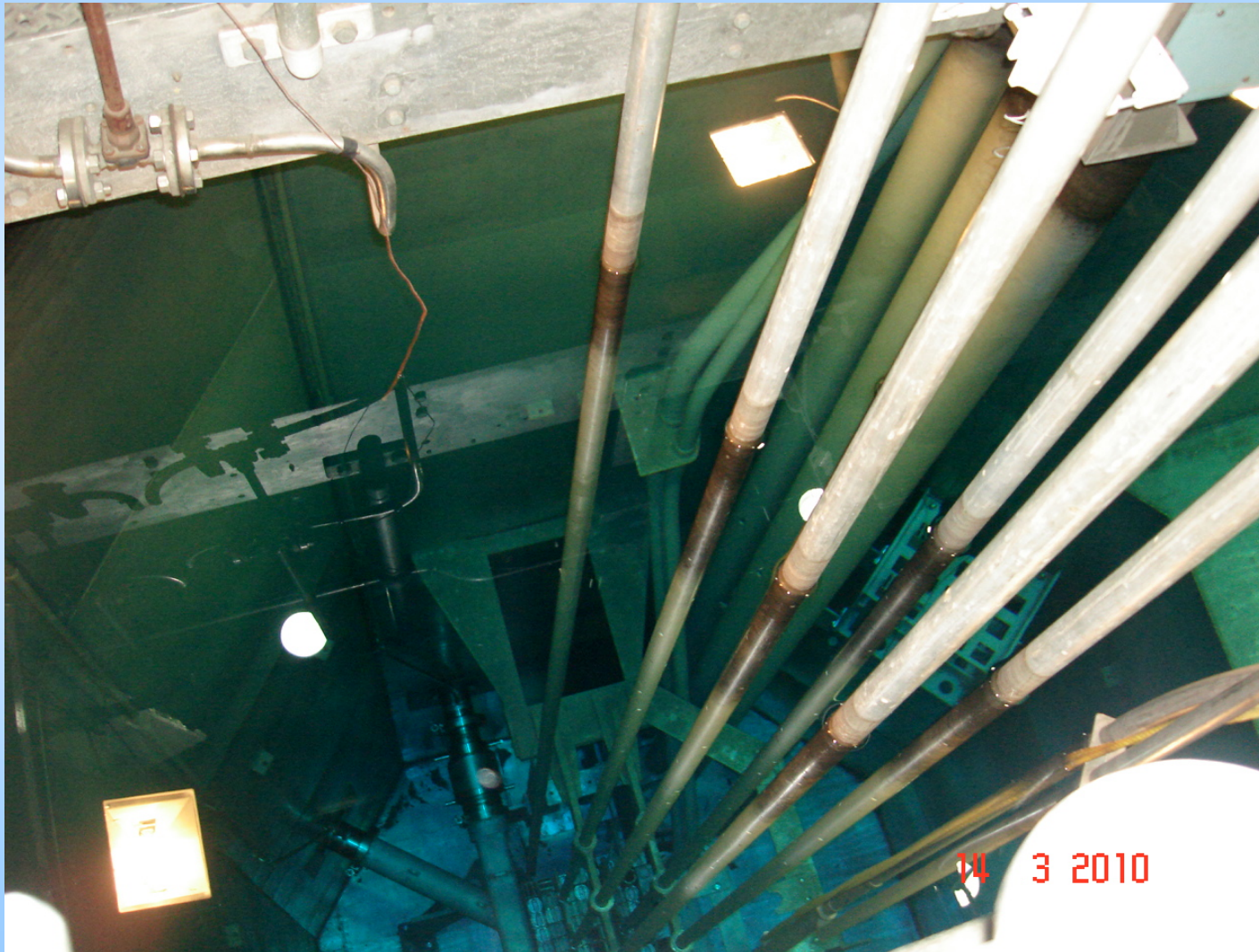




# RESEARCH NUCLEAR REACTOR LA REINA UN DAMAGED (PGA = 0.2 – 0.3 g)



RESEARCH NUCLEAR REACTOR LA REINA  
UNDAMAGED (PGA = 0.2 – 0.3 g).  
REACTOR BARS



# RESEARCH NUCLEAR REACTOR LA REINA UNDATED (PGA = 0.2 – 0.3 g). REACTOR BARS



**RESEARCH NUCLEAR REACTOR LO AGUIRRE - SANTIAGO  
UNDAMAGED (PGA = 0.3 g).**

**CONNECTIONS BETWEEN MAIN AND SECONDARY BUILDINGS**



RESEARCH NUCLEAR REACTOR LO AGUIRRE - SANTIAGO  
UNDAMAGED (PGA = 0.3 g).  
CONNECTIONS BETWEEN MAIN AND SECONDARY BUILDINGS



LOOSE CONCRETE IN ANCHOR BOLTS

# CONVERSION LAB.



# FUEL ELEMENTS





**SAND LICUEFACTION**



IS THE 2010 EARTHQUAKE  
THE LARGEST THAT  
AFFECTS SANTIAGO OR IS  
THE 1730 EARTHQUAKE?

# PERFORMANCE OF HISTORICAL BUILDINGS

# SAN FRANCISCO CHURCH



# SAN FRANCISCO CHURCH



# SAN FRANCISCO CHURCH



WOULD NOT BE THE  
LARGEST EARTHQUAKE

# CONCEPT OF FULLY OPERATIONAL AFTER EARTHQUAKE

# METRO DE SANTIAGO





# METRO DE SANTIAGO



# AEROPORT



# CAMARA CHILENA DE LA CONSTRUCCION BUILDING



# POSTSEISMIC STAGE

# CONCLUSIONS

- IN GENERAL THE CHILEAN SEISMIC CODE NCh 433 OF. 96 “SEISMIC DESIGN OF BUILDINGS” PERFORMED WELL IN REGARD OF LIFE PROTECTION CRITERIA. ONLY 3 BUILDINGS COLLAPSED
- LOW BUILDINGS AND CONFINED MASONRY HOUSES PERFORMED EXCELLENT
- A LITTLE NUMBER BUT IMPORTANT OF HIGH RISE BUILDINGS COULD COLLAPSE IF THE EARTHQUAKE RUPTURE WOULD BE TO THE SOUTH DUE TO DOPPLER EFFECT
- ADOBE HOUSES HAD POOR PERFORMANCE MOST OF THEM COLLAPSED

- THE BRIDGES DESIGNED ACCORDING TO CHILEAN SEISMIC GUIDE HAD AN EXCELLENT PERFORMANCE
- THE FEW BRIDGES AND PEDESTRIAN OVERPASSES THAT COLLAPSED WERE NOT DESIGNED ACCORDING TO THE SEISMIC GUIDE
- ACCELEROGRAMS FOR  $M_w=8.8$  EARTHQUAKE WERE OBTAINED FOR FIRST TIME AT WORLD LEVEL. THESE RECORDS WILL BE MATTER OF FUTURE STUDIES
- POSSIBLE CHANGE OF THE PARADIGM FOR BUILDING DESIGN FROM “LIVE PROTECTION” TO “CONTINUITY OF OPERATION”
- LIQUEFACTION WAS OBSERVED IN MOST OF THE AFFECTED AREA
- MANY SURFACE FAULTS WERE ACTIVATED BY THE EARTHQUAKE

- IMPORTANT DAMAGE AND NUMBER OF VICTIMS WAS MAINLY DUE TO TSUNAMI AND ADOBE HOUSE COLLAPSES
- THE TWO RESEARCH NUCLEAR REACTORS IN SANTIAGO PERFORMED UNCRACKED FOR THE  $M_w=8.8$  CHILEAN EARTHQUAKE.
- THE PGA MEASURED IN SANTIAGO IN STIFF SOIL WAS 0.2-0.3g