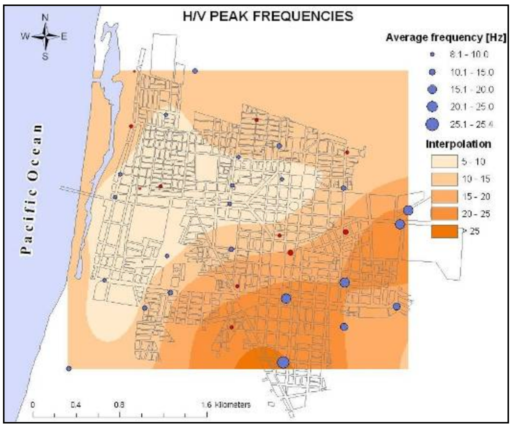
A RECONNAISANCE REPORT

ON

THE PISCO, PERU EARTHQUAKE OF AUGUST 15, 2007



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2007 Pisco, Peru Earthquake Reconnaissance Team

by

Japan Society of Civil Engineers (JSCE),

Japan Association for Earthquake Engineering (JAEE)

and

University of Tokyo

With the collaboration of

CISMID, National University Engineering
(For ambient vibration observations in Pisco)

October 2007

1. INTRODUCTION

On August 15, 2007 at 18:41, a large earthquake (Magnitude, M_W=8.0) hit the central part of Peru’s coast, some 150 km south of Lima. The Peru Geophysics Institute (IGP) estimates Modified Mercalli Intensities of VII-VIII in Pisco, Chincha, and Ica. The earthquake tragically resulted in 519 deaths, 1,291 injured, and more than 650,000 affected people. Totally, some 80,000 dwellings and buildings were damaged or completely destroyed in the regions of Ica, Lima, Huancavelica, Ayacucho and Junín.

Due to the event large magnitude and the heavy damage, Japan Society of Civil Engineers (JSCE) and Japan Association of Earthquake Engineering (JAEE) decided to support the dispatch of a joint team with the Institute of Industrial Science at the University of Tokyo. The objectives of the mission were to investigate damages to dwellings and buildings, considering both structural and geotechnical aspects, and applying the findings to disaster mitigation and reconstruction strategies.

The reconnaissance team consisted of four Spanish speaking persons (two researchers and two students) who spent up to 3 weeks in Peru(Table 1.1). During a 10-day long field survey, several heavily damaged locations, such as Pisco, Tambo de Mora, and Guadalupe, and less damaged locations further away from the epicenter such as Huaytara, Lunahuana, and Pacaran, were visited. Fig. 1.1 and Table 1.2 present further details. The team collaborated with CISMID (Centro Peruano Japonés de Investigaciones Sísmicas y Mitigación de Desastres) of the National University of Engineering, Lima, to perform microtremor measurements in Pisco.

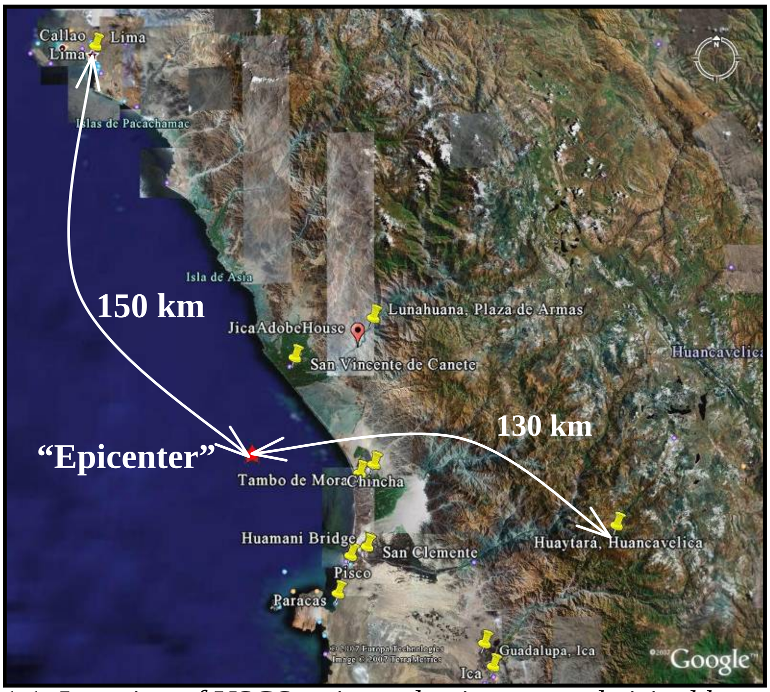

Fig. 1.1. Location of USGS estimated epicenter and visited locations.

In addition to the field activities another 10 days were spent for meetings with several authorities and other organizations in Lima and also for gathering indispensable information such as topographical and geological maps.

The team benefited from discussions with many people, who in spite of their busy schedule in the aftermath of the disaster, spared time and provided us with all available materials and information at their disposal to help us with our activities. Table 1.3 shows a list of the people that we met and to whom we would like to extend our sincere gratitude.

Table 1.1 List of JSCE/JAEE/UT team members

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Table 1.2 Activities carried out by the JSCE/JAEE/UT Mission in Peru

Date	**Activity**
Sept. 4, 2007	Mission (1st group) arrives in Peru
Sept. 5, 2007	Topographical and geological map collection at National Geographic Institute (IGN) and Geology, Mining and Metallurgy Institute (INGEMMET) Interview with Eng. Arellano who was in charge of the design of the rehabilitation of the Huamani Bridge
Sept. 6, 2007	Briefing at the Pontifical Catholic University of Peru (PUCP) Briefing at the Japan-Peru Center for Seismic Investigation and Disaster Mitigation (CISMID)
Sept. 7, 2007	Briefing at the Faculty of Civil Engineering, University of Engineering (FICS) Digital map collection
Sept. 8, 2007	Field survey (Huamani bridge)
Sept. 9, 2007	Logistic arrangements (car rental, hotel)
Sept. 10, 2007	Field survey (San Luis, Nuevo Monterrico, Tambo de Mora)
Sept. 11, 2007	Field survey (Los Libertadores Highway, Huaytara, Huancano, Humay, San Clemente)
Sept. 12, 2007	Field survey (Pisco)
Sept. 13, 2007	Field survey (Pisco, Lunahuana, Canete-Yauyos Highway) Mission (2nd group) arrives to Peru
Sept. 14, 2007	Meeting at FICS for discussing microtremor measurements in Pisco Data preparation for the detailed field survey
Sept. 15, 2007	Field survey (Pantanos de Villa, Playa Totoritas, and microtremor measurements in Pisco) with CISMID
Sept. 16, 2007	Microtremor measurements in Pisco with CISMID
Sept. 17, 2007	Field survey (Guadalupe, Ica, Parcona, Tinguina, Los Molinos) Microtremor measurements (Guadalupe)
Sept. 18, 2007	Field survey (Ica, Tambo de Mora), Microtremor measurements (Ica, Tambo de Mora)
Sept. 19, 2007	Field survey (Lunahuana, Pacaran, Tambo de Mora, Canete-Yauyos Highway) Microtremor measurement (Lunahuana, Pacaran, Tambo de Mora)
Sept. 20, 2007	Briefing at CISMID to exchange information and report survey findings
Sept. 21, 2007	Meeting at INGEMMET and the Peru Geophysics Institute (IGP) to report survey findings and exchange information
Sept. 22, 2007	Meeting with Prof. Kuroiwa, Eng. Jack Lopez and Eng. Jack Lopez-Lara together with the ASCE/TLCEE Team. Briefing with the ASCE/TLCEE Team
Sept. 23, 2007	Field survey (Lima)
Sept. 24, 2007	Meeting at the Ministry of Transportations and Communications (MTC) together with the ASCE/TLCEE Team Briefing at the Japanese Embassy in Lima and SENCICO to report survey findings and exchange information
Sept. 25, 2007	Meeting at INDECI and the Ministry of Economy and Finances to report survey findings and exchange information
Sept. 26, 2007	Meeting at the IGN to collect information Meeting at the Swedish Consulate toe report survey findings and exchange information Fly back to Japan
Sept. 28, 2007	Arrive to Japan

Table 1.3. List of people interviewed during the JSCE/JAEE/UT survey

Agency	People met
Ministry of Economy and Finance (MEF) Direction of the Public Sector Multi-Annual Programming	Eng. Miguel Priale Ugas (Director General) Eng. Jorge Escurra Cabrera (Consultant-Coordinator of the Program for Prevention and Rehabilitation of the Regions affected by Natural and Human Induced Disasters) Mr. Mitsuo Sakamoto (JICA Advisor on ODA Loans) Mr. Jose Garcia Pisco Mr. Adhemir Ramirez Rivera
Ministry of Transportation and Communications (MTC) (unfortunately it was not possible to obtain the list of all the participants from the MTC side)	Dr. Carlos R. Valdez Velasquez Lopez (Director General, Comunications Secretaria) Mr. Juan Carlos Paz Cardenas (Director General of Aquatic Transportation)
Municipality of Pisco (Urban Development Office)	Eng. Hugo Suarez Eng. Raul Doroteo Eng. Nestor Lopez del Mar Eng. Jose Uribe
Municipality of Huaytara	Ms. Lidia Sedano Quintanilla
Municipality of Parcona	Eng. Cesar E. Guillen Vasquez
Municipality of Lunahuana	Ms. Cesarían Vera Gonzalez del Valle Ms. Nancy Villanueva Ms. Elia Luyo
National Institute of Civil Defense (INDECI)	Retired Colonel Ciro Mosqueira (Sub-director) Eng. Alfredo Perez Arch. Alfredo Zerga
National Service for Training for the Construction Industry (SENCICO)	Eng. Carmen Kuroiwa Horiuchi (Head of the Standardization and Research Department) Eng. Gabriela Esparza Requejo
Geology, Mining and Metallurgy Institute (INGEMMET)	Eng. Lionel Fidel Smoll Dr. Jose Machare Ordonez Geologist Carlos Lenin Benavente Escobar Ms. Yanet Antayhua Vera
National Geographic Institute (IGN)	Colonel Cesar Nicolas Alva Baltazar
Peru Geophysics Institute (IGP) (unfortunately it was not possible to obtain the list of all the participants from the IGP side)	Dr. Hernan Montes Ugarte Dr. Hernan Tavera Dr. Laurence Audin-Hourton
CISMID National University of Engineering Faculty of Civil Engineering (FICS)	Dr. Jorge Alva (Dean of FICS) Dr. Carlos Zavala (CISMID Director) Dr. Miguel Estrada Eng. Fernando Lazares Dr. Zenon Aguilar

Agency	People met
Pontifical University Catholic of Peru	Dr. Marcial Blondet (Dean of the Graduate School) Eng. Angel San Bartolome Eng. Walter Silva Eng. Gladys Villagarcia
San Luis Gonzaga National University	Eng. Rene Oswaldo Canchasi Vega (Chief of the Soil Mechanics Laboratory)
COVIPERU	Eng. Julio Mujica (telephonic communication)
Individuals	Prof. Julio Kuroiwa (INDECI Senior Advisor) Eng. Francisco Arellano (Consultant) Eng. Jack Lopez (Consultant) Eng. Jack Lopez-Jara (Consultant) Ms. Shizuko Matsuzaki (EVAA NPO)
Ica Association of Civil Engineers	Ing. Luis Ordonez
San Juan de Dios Hospital (Pisco, Ica)	Dr. Ricardo Cabrera
San Juan Bautista School (Huaytara, Huancavelica)	Mr. Gil Josué Huaroto Arango (Interim Director)
Beatita de Humay 22451 (Humay, Ica)	Mr. Fidencio Diaz Condori (President of the Students Association)
San Luis Gonzaga School (Ica)	Mr. Pedro Eduardo Falcon Guerra (Director) Ms. Mili Alvaro Lopez (Subdirector)
Japanese Embassy in Lima	Eng. Akihiko Tasaka (1st Secretary) Arch. M. Sato
Swedish Consulate	Mr. Stefan E. Sandberg (Consul) Rev. Nicklas Fahlgren

1.1 Affected area

Peru is divided into 25 administrative regions (formerly departments). Each region has number of provinces, and each province consist of districts. In this report, the term affected areas refer to the most heavily damaged areas, i.e Pisco, Chincha, and Ica Provinces in the Ica Region, Canete and Yauyos in the Lima Region, and Huaytara and Castrovirreyna Provinces, in the Huancavelica Region.

1.2 Economic impacts

It is still early to estimate the economic impacts of the 2007 Pisco Earthquake, especially the indirect losses. However, the Ministry of Economy and Finance (MEF) has already made a preliminary estimation of the public infrastructure reconstruction costs which is shown in Table 1.4. In the table, the item Housing refers to the S/.6 000 (roughly US$2 000) that the government has promised to give the people who lost their houses. Note that the estimation does not include all the affected provinces.

Table 1.4. Estimation of public infrastructure reconstruction cost (after MEF [1])

Sector	Million US$
Housing	30.61
Sanitation[1]	49.64
Power supply[2]	23.25
Transportation	33.00
Health[3]	15.19
Education	68.99
Total	220.68

[1] Only water supply and sewage of Pisco, Canete, Ica and Chincha
[2] Power supply system of Pisco, Ica, and Chincha
[3] Only Canete Province and Ica Department

MEF also estimated that the earthquake will cause the Ica Departmnent Gross Internal Product to fall 6% in 2007.

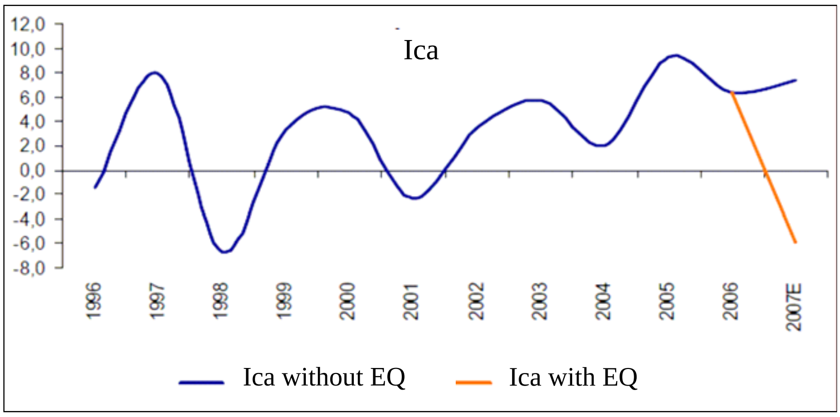

Fig. 1.2 Variations of the Gross Internal Product in Ica Department (after MEF [1])

In the last years, Ica has represented 2.4% of the National Gross Internal Product, which will grow 0.38 percent units less than forecasted for 2007, due to the event.

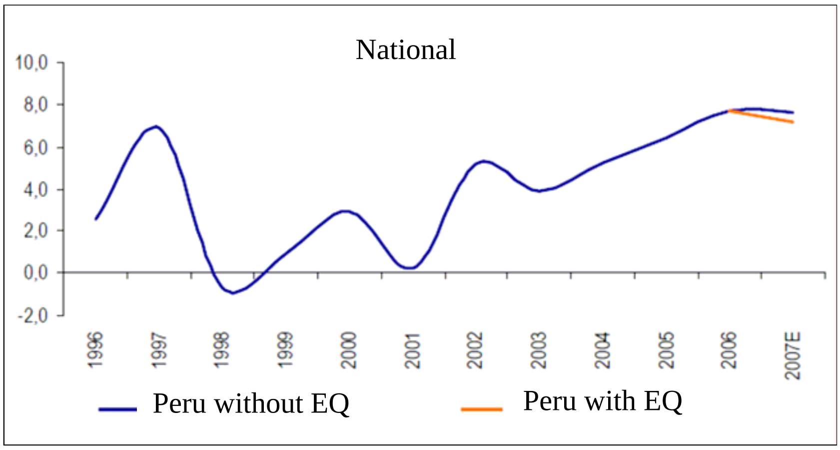

Fig. 1.3 Variations of the National Gross Internal Product (after MEF [1])

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2. SEISMOLOGICAL ASPECTS

2.1. Tectonic and Seismological background

The Pisco Peru earthquake was caused by the subduction of the Nazca plate beneath the South American Plate (see Fig. 2.1. after Degg and Chester [1], who give a nice overview of Seismic and Volcanic hazards in Peru). The amount of movement is approximately 7-8 cm/ year. Several large magnitude earthquakes have occurred in the historical period (see Fig. 2.2), most recently in 2001 in the southern part of Peru (see e.g. [14]). Tavera et. al. have estimated a “seismic gap” in the subduction zone at the height of Pisco and Ica (see red mark in Fig. 2.2.)

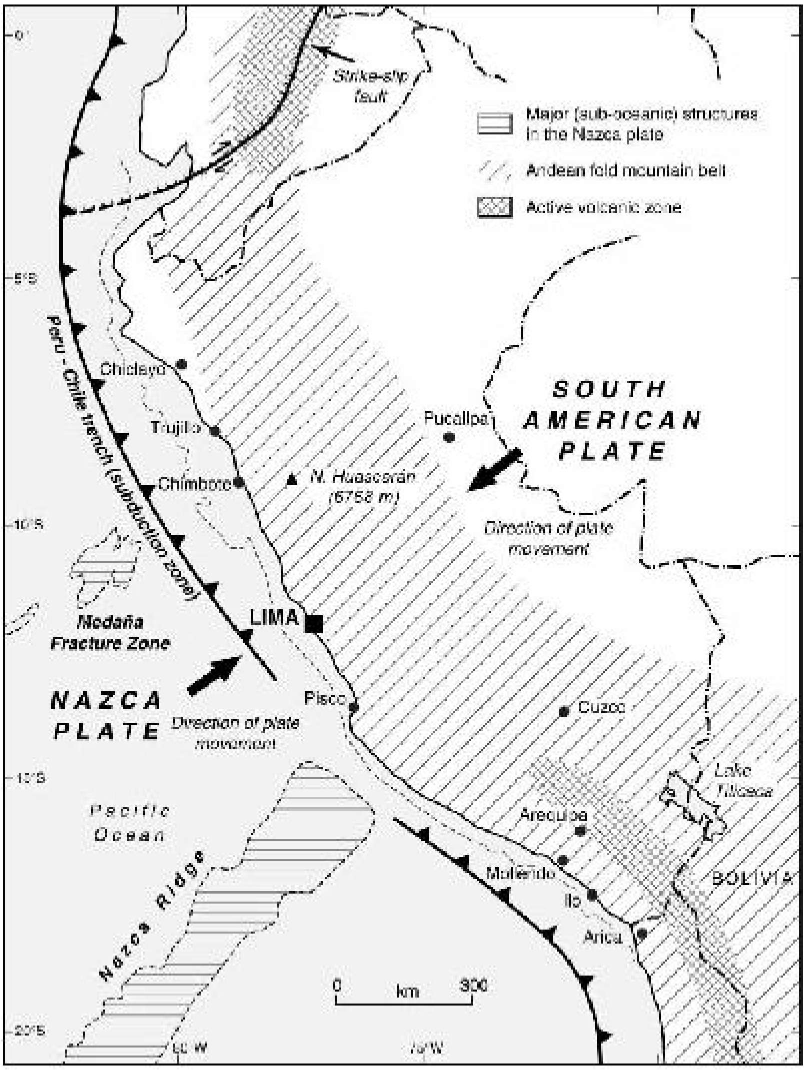

Fig. 2.1. Tectonic map. (after Degg and Chester, 2005, [1]

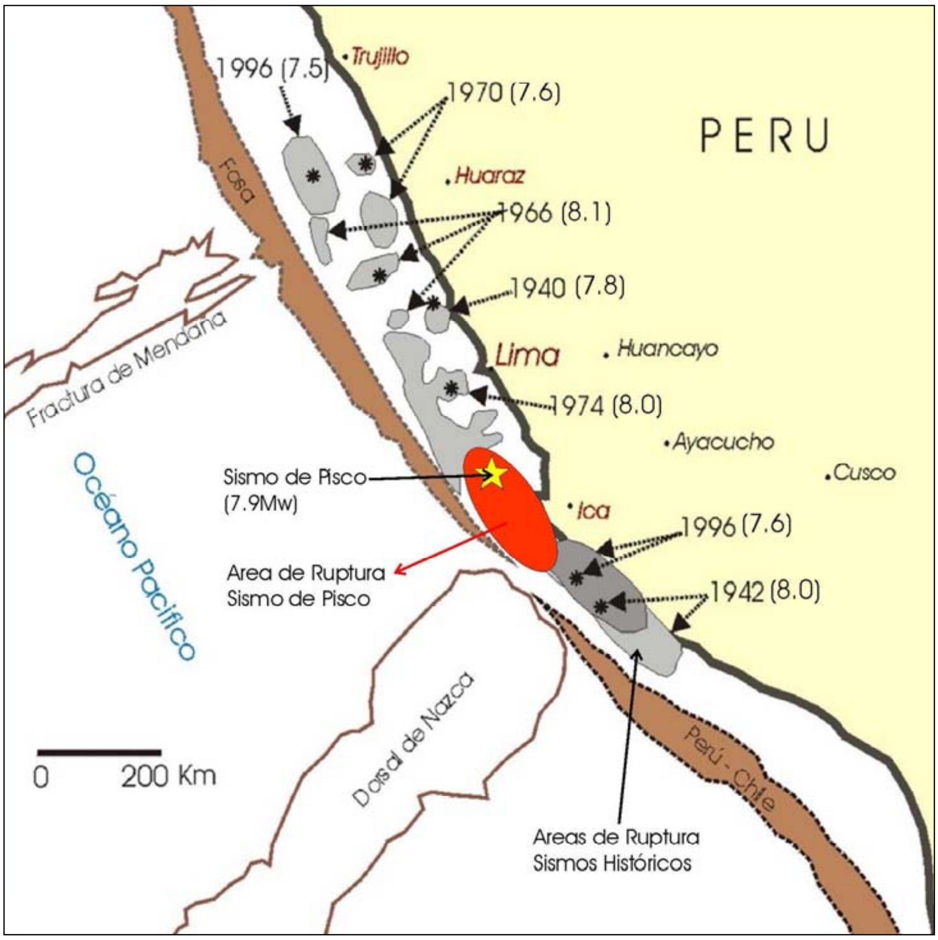

Fig. 2.2. The Pisco Peru earthquake ruptured an identified seismic gap. (after Tavera et. al. 2007, [3].)

2.2. The August 15 earthquake

August 15 18:41 local time a magnitude 8 (Mw=moment magnitude) class earthquake occurred of the middle part off Peru's coast, close to the cities of Chincha, and Pisco. The duration of the earthquake was very long with over 2 minutes of strong ground shaking at Ica (see Fig. 2.5). The local/Richter magnitude computed by IGP was 7.0 (M_L). (The use of different magnitude by seismologists caused confusion since laymen take them for the same thing, which they are not. This confusion was amplified by a rumor that reconstruction financial support would depend on the magnitude). The epicenter location from Institute of Geophysics of Peru (IGP), University of Harvard, and USGS/NEIC differs by some 10 to 20 kilometers as can bee seen in Fig. 2.3. Its depth was reported as 39km (USGS), 33.3 km (Harvard), and 26 km (IGP).

2.2.1. Intensities

Intensities were estimated by both USGS and IGP based on interviews and according to the Modified Mercalli scale. The IGP estimates MM VII-VIII in Pisco, Chincha, and Ica [4]. An intensity map is shown in Fig. 2.4 (after [1]). Intensities have been further discussed in [7] from which

Table 2.1 was adapted. In [7] a logarithmic function is fitted to graph with intensities versus hypocentral distance. This type of fitting can allow for evaluating points with intensities deviating from the fitted curves. Such deviations could be due to effects of soil amplification, directivity, fling, which warrant further scientific and engineering studies.

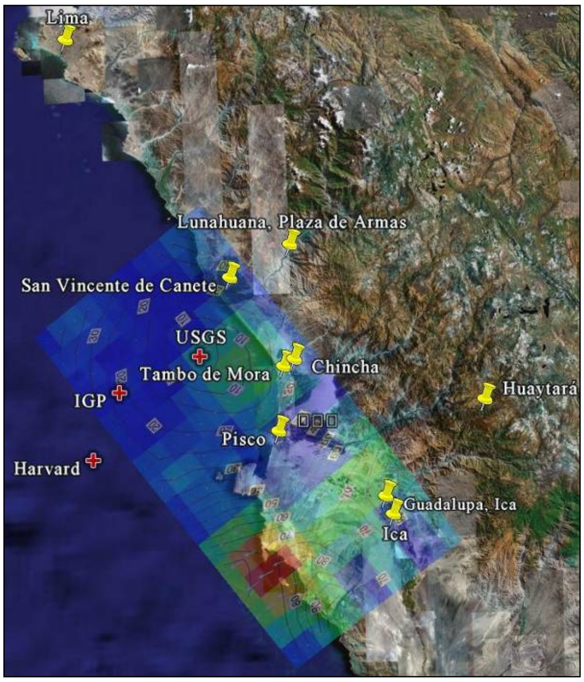

Fig. 2.3. The epicenter location from Institute of Geophysics of Peru, University of Harvard (CMT), and USGS/NEIC differs by some 10 to 20 kilometers. (Google Earth map).

Fig. 2.4. Modified Mercalli intensities according to the Institute of Geophysics of Peru. [1].

Table 2.1. Table of intensities (after [7])

Town		Region	Province	Intensity	Hypocentral Distance [km]
1	Lurín	Lima	Lima	5.5	160
2	Pucusama	Lima	Cañete	5.5	138
3	Chilca	Lima	Cañete	6	133
4	Mala	Lima	Cañete	6.5	121
5	Asia	Lima	Cañete	6.5	108
6	Coayllo	Lima	Cañete	7	116
7	Lunahuana	Lima	Cañete	7	111
8	Cerro Azul	Lima	Cañete	6.5	87
9	Pauyo	Lima	Cañete	6	103
10	San Vicente de Cañete	Lima	Cañete	7	86
11	Chincha Alta	Ica	Chincha	7.5	82
12	Tambo de Mora	Ica	Chincha	7	76
13	Chincha Baja	Ica	Chincha	7.5	79
14	San Clemente	Ica	Pisco	7.5	77
15	Pisco	Ica	Pisco	8	71
16	San Andrés	Ica	Pisco	7.5	70
17	Paracas	Ica	Pisco	7.5	70
18	Pozo Santo	Ica	Pisco	7.5	87
19	Guadalupe	Ica	Ica	7.5	119
20	Ica	Ica	Ica	7	127
21	Tate de la Capilla	Ica	Ica	6.5	132
22	Santiago	Ica	Ica	7	133
23	Ocucaje	Ica	Ica	6	146
24	Palpa	Ica	Palpa	5	199
25	Nazca	Ica	Nazca	5	238
26	San Juan	Ica	Nazca	5	259
27	Talara	Piura	Talara	2	1123
28	Chiclayo	Lambayeque	Chiclayo	2	837
29	Cajamarca	Cajamarca	Cajamarca	3	749
30	Chachapoyas	Amazonas	Chachapoyas	2	838
31	Moyobamba	San Martin	Moyobamba	2	848
32	Trujillo	La Libertad	Trujillo	3	666
33	Chimbote	Ancash	Santa	4	549
34	Huaraz	Ancash	Huaraz	4	469
35	Huanuco	Huanuco	Huanuco	4	423
36	Cotobamba	Loreto	Ucayali	3	730
37	Pucallpa	Ucayali	Coronel Portillo	3	636
38	Barranca	Lima	Barranca	5	345
39	La Merced	Junin	Chanchamayo	4	333
40	Canta	Lima	Canta	5	249
41	Matucana	Lima	Huarochiri	5	210
42	Lima	Lima	Lima	5	187
43	Huancayo	Junin	Huancayo	4	247
44	Huancavelica	Huancavelica	Huancavelica	5	221
45	Calango	Lima	Cañete	6	135
46	Ayacucho	Ayacucho	Huamanga	4	283
47	Puquio	Ayacucho	Lucanas	4	309
48	Chala	Arequipa	Caraveli	4	367
49	Abancay	Apurimac	Abancay	3	421
50	Cusco	Cusco	Cusco	3	519
51	Cotahuasi	Arequipa	La Union	3	454
52	Camana	Arequipa	Camana	3	548
53	Arequipa	Arequipa	Arequipa	2	642
54	Mollendo	Arequipa	Islay	3	635

2.3. *Seismic network*[JJ1]

2.3.1. Number of organizations and stations

Five organizations (to our knowledge) have accelerometers installed in different locations in Peru. The Institute of geophysics of Peru (IGP) and CISMID have both their independent national networks of some 15 stations each; CERESIS, SEDAPAL and Pontific Catholic University of Peru (PCUP) also have their own accelerometers. Some of the organizations mentioned above have records available on their websites (see Table below.)

Table 2.2. Organization with downloadable acceleration data.

Organization	URL
CISMID	http://www.cismid-uni.org/descargas/acelerogramas.zip
CERESIS	http://www.ceresis.org/informacion/acelerogramas_ica20070815/index.php
PCUP	Included in the CERESIS website

2.3.2. Earthquake Records and Strong Ground Motion amplification

Peak ground accelerations (PGA) from the different seismic networks are given in *Table 2.3* (compiled from [5] and [6].) The maximum acceleration observed was 488 gals in Parcona (IGP station), to the east of Ica and 334 gals at the University of Ica (CISMID station, see also Fig. 2.5). The other accelerometers shown in *Table 2.3* are located in Lima, further away from the fault and the maximum accelerations here are 115 gals that were observed in the district of La Molina (Rinconada, CERESIS station.). The ground motion recorded at Callao is shown in see Fig. 2.5. The accelerometer in Guadalupe, closest to the epicenter, did unfortunately not work properly so the two accelerometers in Parcona and at the university of Ica are the ones closest to the fault.

The earthquake records in Lima show how the soil conditions affect the ground motions with rock sites having PGAs of 20 gals, while PGAs of over 100 gals soft soil sites like the port of Callao and La Molina, i.e. an amplification of 5 times. Similar amplification of ground motion is also likely to have occurred in Tambo de Mora, Chincha, Pisco, Guadalupe, etc, all located upon alluvial and marine deposits. An evaluation of possible amplification levels in Pisco is discussed in Chapter 3.

Table 2.3. Accelerometer locations and Peak ground accelerations. The first two locations are outside Lima closer to the epicenter, the rest are in Lima some 150-200 km from the epicenter.

Station	Location	PGA cm/s^2
PCN	Parcona	488.0
Ica2	Uni. of Ica	334.1
RIN (Rinconada)	La Molina	115.0
CAL (Callao)	Callao	101.0
ANR (A. Nac. R)	S. de Surco	85.3
MOL (Molina)	La Molina	78.7
CSM (Cismid)	Rímac	73.9
PUCP (U. Católica)	San Miguel	67.0
MAY (Mayorazgo)	Ate Vitarte	59.7
CLD-CIP	San Isidro	58.8
CER (Ceresis)	San Borja	58.7
ANC (Ancón)	Ancón	58.4
E1 (Estanque-1)	Santa Anita	54.8
LMO (La Molina)	La Molina	25.3
NNA (Ñaña)	Ñaña	22.1
E2 (Estanque-2)	Santa Anita	20.6

Interestingly all records have two parts with large accelerations, separated by some 50 to 70 seconds as seen in Fig. 2.5. Furthermore for the records closer to the epicentral area (Parcona, University of Ica) the 1st part is bigger than the 2nd, but for all records in Lima the 2nd part have larger accelerations than the 1st part. The time difference between the two pulses is some 50 seconds in Ica and 70 seconds at Callao, Lima. This suggests that the second pulse is due to a rupture of an asperity on the southern part of the fault, further away from Lima, and closer to Ica, which corresponds to Yagi's [8] finite fault solution. Fig. 2.6 shows the response spectra for the Ica 2 and Callao, Lima stations. The peak response occurs at a period of 0.49 seconds at Ica 2 and 0.65 seconds at Callao. More about the two pulses in the records and Peak ground accelerations dependency on the soil conditions have been investigated in [5] and [6].

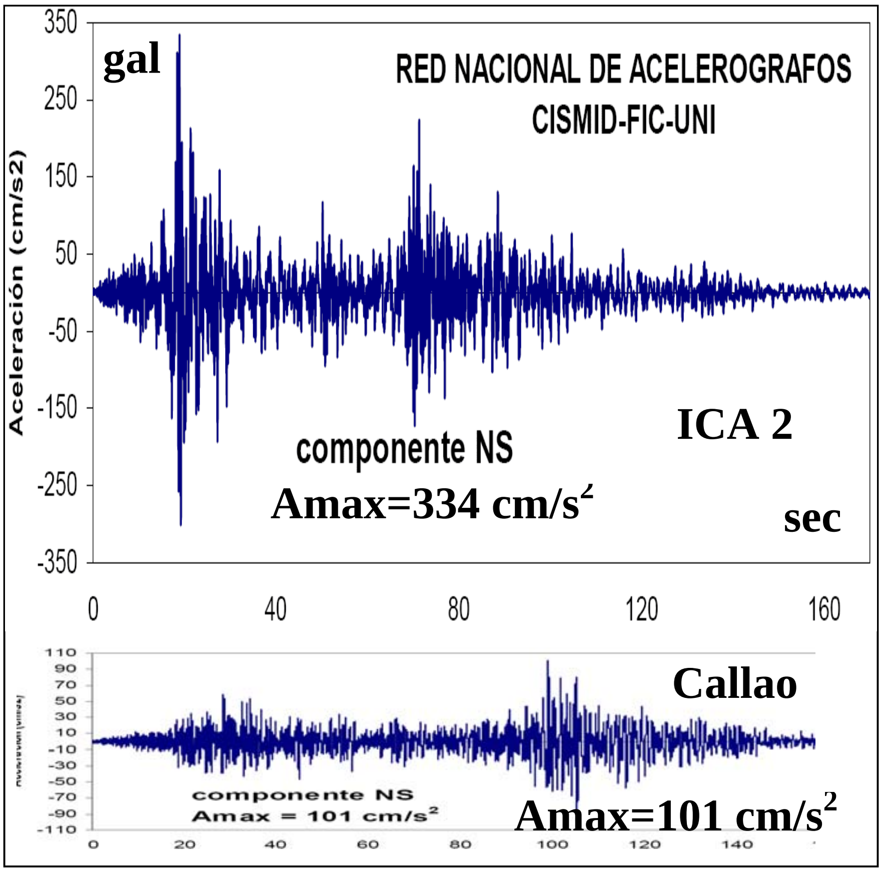

Fig. 2.5. Acceleration records at ICA2 in Ica, and at Callao (port of Lima). [15]

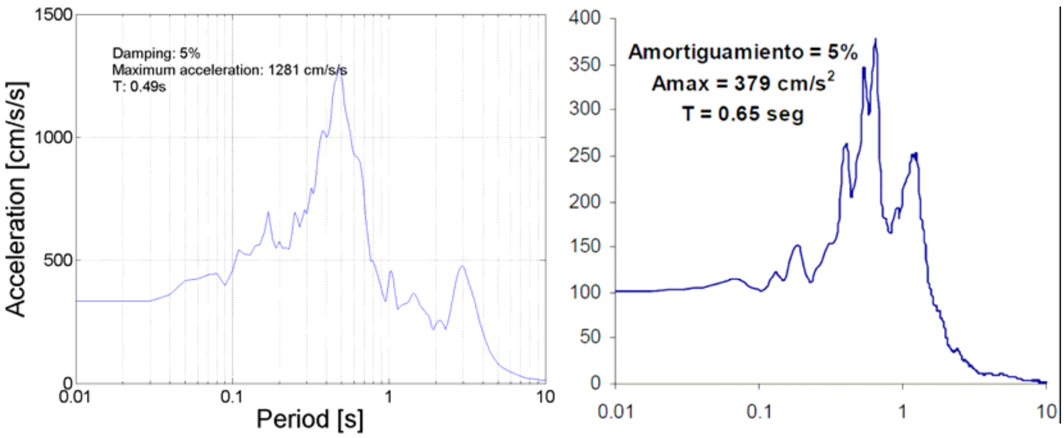

Fig. 2.6. Response Spectra for acceleration records at ICA2 in Ica, and at Callao (port of Lima). (Callao record after [15])

2.4. Finite Fault solutions

We are aware of five different researchers finite fault solutions [8]-[12]. While there are differences in the maximum slip in the solutions as seen in Fig. 2.7, there is a general trend in all solutions of two major areas of slip (asperities), one located close to the epicenter in near Chincha, and the other further south, beneath and to the west of Ica. Perfettini [13] compares and discusses the results obtained by Yagi [8], Konca [11], and

Vallée [12], and suggests that the model by Yagi [8] corresponds well to several types of field observations.

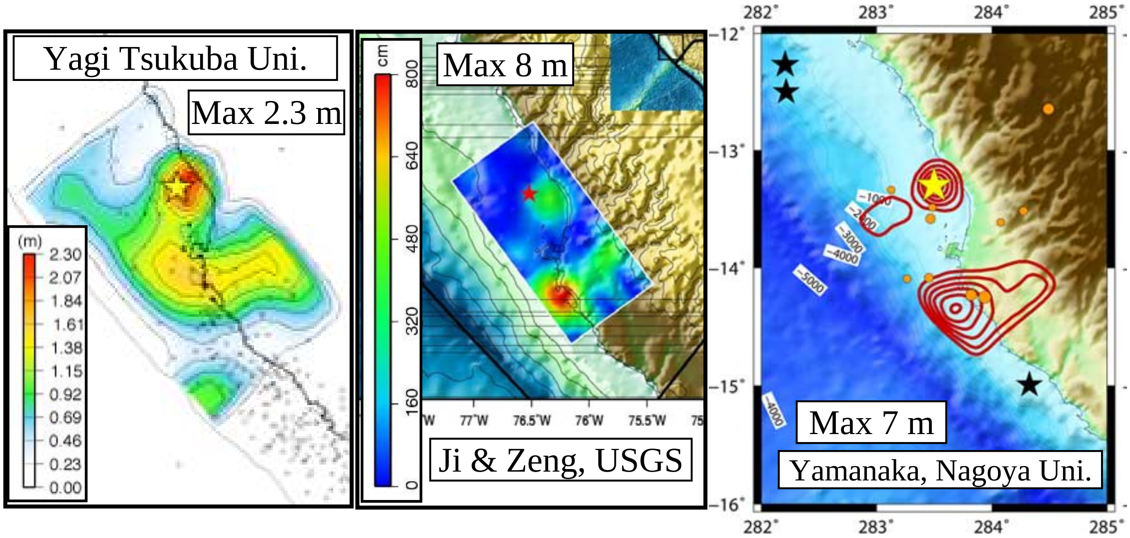

Fig. 2.7. Finite fault solutions after Yagi [8], Ji and Zeng [9], and Yamanaka [10].

2.5. Recommendations

Strengthen the system for sharing strong ground motion recorded information, through, for instance a common Internet platform from where the information of all relevant institutions can be downloaded as soon as it is available. E.g. instrumental intensity maps based on all records could be provided.

Adding more seismographs to the networks, especially to the bigger cities, and converting analog instruments to digital, would e.g. allow for quicker estimation of affected areas.

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