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DISASTER RISK MANAGEMENT IN DEVELOPING COUNTRIES AND THE IMPORTANCE OF INTERNATIONAL COOPERATION

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ABSTRACT

During the last decade very large and unexpected megadisasters have occurred: the 2004 Indian Ocean Tsunami, and the Great East Japan Earthquake and Tsunami in 2011. Also the 2010 Maule, Chile earthquake, in addition to the 1994 Northridge earthquake in California, the USA and the 1995 Kobe, Japan earthquake, have left a wealth of results that are permitting rapid advancement in science and technology. For example, the 2004 Indian Ocean Tsunami impulsed the studies of paleotsunamis, and the 2011 Great East Japan Earthquake and Tsunami occurred in one of the world best instrumented regions. There, very large numbers of geophysical measurements, horizontal and vertical coseismic displacements, were made. The deformation of the sea bottom provides information for understanding how tsunamis are generated by megathrust earthquakes in subduction zones. The observed coseismic displacements and their interpretation were considered as one of the most important advancements in science in 2011 by an article on the journal SCIENCE.

A large number of investigations have been made, institutionally and individually. One of the most important and useful ones in disaster prone countries is the report of the Government of Japan, GFDRR and World Bank entitled “Learning from Megadisasters”. This report covers in six clusters, all phases of Disaster Risk Manage (DRM), and for every case there are special recommendations for developing countries.

Section 2 of this paper includes the direct experience for facing future disasters based on their relative development. Chile and Colombia have had direct experiences in disasters a few years before the 2010 Maule, Chile earthquake and the 1999 Eje Cafetero, Colombia earthquake. Both countries responded adequately to those events. The Venezuelan Caribbean has had debris flow disasters about once a century. So on the debris deposit fans, modern beach resorts were developed. The scenario for the disaster was ready, and it occurred in December 1999, when some 13,000 persons lost their lives and the material losses amounted to over US$ 10,000 million.

A destructive earthquake struck Lima, Peru’s capital city in 1974. Most of its inhabitants have not had any direct experience of an earthquake. In spite of the fact that two recent investigations on the possible effects of an earthquake and tsunami in Lima concluded that the death toll would be high and the material losses huge, the best word to describe the attitude of Lima inhabitants is “indifference”: this is a challenging task that needs to be faced with decision and energy.

In Section 3 is included the advancement in studies on paleotsunamis and coseismic deformations which are permitting among other actions, practical engineering applications. In Section 4 as a case study of the benefits of international cooperation, the example of Peru is presented. In Section 5, a summary of the most important lessons left by disasters occurred in Asia and the Americas during the last few years is included.

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1. INTRODUCTION

The risk for life and properties of people living in the Third World countries, located in disaster-prone regions is “very high” or “high”, depending on their relative development, mainly the level of education in general, and particularly education in disaster risk reduction, as well as recent direct experience in facing large disasters. International cooperation has played a very important role in reducing the risk of disaster in those countries, as highlighted in this paper.

The countries affected by the 2004 Indian Ocean tsunami, which left some 230,000 mortal victims, who didn´t have any tsunami experience during the 20th century (e.g., USGS Web-Site-1); and by the 2010 Haiti earthquake with a death toll of some 70, 000 to over 200, 000, depending on the data source, as USGS Web-Site-2 or Munich Re (2004), might be examples of the first group of nations. In the second group the South American Andean countries may be included: Chile, Colombia, Venezuela and Peru, with some differences among them. Lessons from disasters that have struck those countries in the last few decades, and how those events had been handled before new disasters affected those nations, are included in Section 2 of this paper.

The largest disasters that have occurred during the last 20 years have left important lessons: the Indian Ocean Tsunami of December 26, 2004; the earthquakes at Maule, Chile, February 27, 2010; and the Great East Japan (alias Tohoku-Oki, Japan) Earthquake and Tsunami, occurred on March 11, 2011. On the last two megadisasters, hundreds of papers have been produced investigating both events, institutionally and individually, and these have been mainly summarized by researchers of the University of Chile (University of Chile, 2012) and by the Earthquake Engineering Research Institute (EERI, 2012); and for the Great East Japan event, e.g., in a comprehensive report by the Government of Japan, Global Facility of Disaster Risk Reduction (GFDRR) and the World Bank (i.e., Ranghieri and Ishiwatari, 2014); as well as the EERI (2013). They are very important documents that need to be made known worldwidely and include special recommendations on Disaster Risk Management (DRM) for developing countries. They consider the whole process of DRM, including business continuity after a disaster that is a new matter for most developing countries, and should be included in their DRM to prevent problems of bankruptcy of large, medium and small businesses.

After the 2004 Indian tsunami disaster, the investigations on paleotsunamis received an important impulse, and in the 2011 Great East Japan Earthquake and Tsunami, which occurred in one of the world’s best instrumented regions, coseismic horizontal and vertical displacements were recorded, as never before, precise enough to improve the understanding of how earthquakes and tsunamis are generated in subduction zones. For example, in SCIENCE, June 17, 2011 issue, it was reported that coseismic recordings and their interpretation were regarded as one of the outstanding scientific advancements in 2011 (i.e., Simons et al., 2013). Hashimoto (2013) in a special issue of “Earthquake Spectra” (EERI , 2013) reported on the 2011 Tohoku-Oki earthquake and tsunami, taking as reference Simons et al. (2011) to illustrate the meaning of horizontal and vertical coseismic displacement. In the whole area were operating continuously more than 1,200 recording sites of the Global Positioning System (GPS) called GEONET, installed and operated by the Geospatial Information Authority of Japan (GSI) (e.g., GSI Web Site). The horizontal coseismic displacement during the main shock extracted from the continuous records of GPS that is west to east of Honshu exceeded 4.3 m horizontally in at the Pacific coast and about 1.0 m in the border of the Japan sea, including some 0.4m on the Sado island in the Japan sea. The peak horizontal GPS measured displacements was approximately 0.44 m. in this case. Using the GPS observation data, as well as those of sea floor pressure gauge, seafloor deformation model was made. This model predicts the maximum seafloor subsidence of about 2.0 m located 50 km offshore Sendai and Kamaishi and the maximum uplift just under 9.0 m some 50 km from the trench. On land, the measured observed subsidence was 0.50 m.

These latest advancements in science and technology are permitting important practical engineering applications also, such as estimating the return period of 1,000 years for tsunamis; it was impossible to do so only a few years ago, due to the lack of necessary historical data, for example, along the South America’s west coast, where existing data go back only some 500 years as included in Section 3 of this paper.

In Section 4 of this report the Peru’s case study is included as an example of how effective international cooperation is for reducing disaster in a developing country.

Peru has received benefits from international cooperation mainly by training in the host countries, for example, in known universities in the USA, Japan and other countries. The International Institute of Seismology and Earthquake Engineering, Building Research Institute (IISEE, BRI) located in Tsukuba, Japan under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the Government of Japan is a special case to mention as an institution specializing in disaster reduction applied to Seismology, Earthquake Engineering, and Tsunami Disaster Management.

In over 50 years of activities the IISEE, as of September 2014 has trained 1,653 participants from 99 developing countries as included in the recent volume of its Year Book (IISEE, 2014). From 1963 to 1972 UNESCO supported IISEE, to maintain its training courses (IISEE Web Site).

Indonesia and Peru are the countries with the greatest number of participants at the IISEE. In the case of Peru, its participation was increased due to the 1970 Ancash, Peru earthquake with the largest death toll in the Americas in the 20th century: 67,000 fatal victims (e.g., CRYRZA, 1972).

Peru’s case study is included to show the great benefits that this developing country has received from international cooperation agencies and from governments that have developed high technology in disaster risk reduction, such as Japan and the USA.

In Section 5 of this paper, “Concluding Remarks and Recommendations”, an effort was made to summarize results of important advancements in science and technology for reducing disasters, developed during the last few years, and how developing countries may improve the results of technical assistance for the direct benefit of those countries focused on the poor and vulnerable people.

2. DISASTER RISK REDUCTION IN THE SOUTH AMERICAN ANDEAN COUNTRIES

2.1. An Overview

The general knowledge on disaster risk management and the direct experience of a generation that has suffered the consequences of a great disaster have an important influence on the attitude how to prepare and to respond to future disasters.

Chile responded adequately after the 2010 Maule, Chile earthquake and tsunami, and Colombia rehabilitated and reconstructed the city of Armenia, Dept. of Quindio affected by the 1999 Eje Cafetero earthquake with efficiency and according to the established timetable.

Since the 1939 Chillán, Chile earthquake, with a death toll of 30,000 (USGS Web Site-3) Chile has been struck by destructive earthquakes practically during every generation. Colombia had an unfortunate mismanagement of the Nevado del Ruiz volcanic eruption disaster when 23,000 persons lost their lives in the city of Armero with its total 30,000 inhabitants. Volcanologist Dr. John Tromblin from UNDRO, Geneva, provided the author the volcano hazard map of Armero in November, 1985. But Colombian learnt the lessons. Only 14 years later they did a good job in the rehabilitation and reconstruction of the city of Armenia affected by the 1999 Eje Cafetero, Colombia earthquake. There was a good planning, coordination and provision of the necessary funds. The central, regional and local governments did a good job.

The Venezuelan Caribbean north of Caracas has suffered very destructive flooding about once every hundred years, so when the 1999 Venezuela debris flow and flash flood disaster struck the area, modern urban beach resorts had been developed occupying the hazardous alluvial fans, practically the only available flat area in the narrow strip between the Cordillera de la Costa, which runs parallel to the Venezuelan Caribbean coast and the valley of Caracas where, the Venezuela capital city is located. So the disaster scenario was ready for the 1999 event (Larsen et al., 2001).

Lima, the capital city of Peru, houses 9.5 million inhabitants. In 1974 the last destructive earthquake struck the central western coast of Peru, where Lima and its nearby seaport, Callao, are located (USGS Web Site-4), so most of the people living in the area who are under 40-43 years old do not have any direct experience of earthquake disaster.

In spite of the fact that the Geophysical Institute of Peru (IGP) is warning that there is a seismic gap in the area, and two recent cooperative projects founded by the European Commission’s

Humanitarian Aid and Civil Protection Department (ECHO) and the Government of Japan, have found that if an earthquake of large magnitude occurs in the Lima area, the mortal victims might be numerous and the material losses might also be huge, the reaction of civil society is very poor. However to revert this situation which is difficult and an important challenge, the official institutions and the civil society need to be face this situation necessarily, with determination and energy.

2.2. Chile

The 1939 Chillán, Chile earthquake killed some 30,000 people and motivated the development of Earthquake Engineering in that country. During the 1940s and 1950s, Santiago de Chile and Los Angeles, California, the USA had restrictions regarding the height of buildings, limiting them to 10 stories high.

The Maule Chile earthquake (February 27, 2010, Mw 8.8) had a death toll of 709 persons and the material losses were over US$ 30,000 million according to the Report of Situation Nº 10 from the United Nations Resident Coordination Office to the Government of Chile of March 30, 2010. Since the early 20th century practically each generation experienced a destructive earthquake, so Chileans are constantly aware of the seismic and tsunami risk, and most people know how to face emergencies. For example, during the early morning on February 27, 2010 the tsunami warning was officially canceled due to a technical error. However, people felt a large earthquake that lasted for more than three minutes, so according to their own knowledge, they knew that they needed to evacuate the tsunami inundation zones to high locations. This reaction is the result of education such as the Earthquake and Tsunami education in Chile, which is one of the most advanced in Latin America, together with the “Kamaishi Miracle” (e.g., Sawaji, 2012). These two cases show how critical is education on disaster risk reduction for protecting people.

Chile was struck in 1960 by the largest earthquake since seismic magnitude has been estimated using instrumented recordings. It was the 1960 Valdivia, Chile earthquake of Mw 9.5. It generated a large tsunami that crossed the Pacific Ocean to cause more than 61 mortal victims in Hawaii, and 340 in Sanriku, Japan, known to be one of the most sensitive locations to tsunami effects in the world. Also, 32 persons lost their lives in the Philippines (USGS Web Site-5). The Hawaiian Islands are the product of a hot spot emerged from the ocean bottom by successive emissions of lava. So there is deep ocean water near their coast, causing tsunami run ups to be unusually high, since there is practically no energy dissipation on the sea bottom near the islands.

The first tsunami wave reached east of Honshu at Sanriku coast, in some 20 hours. Here, there is also deep ocean water near the coast, with U, V, and W-shape bays, that concentrate the tsunami energy in the bays tips. During the March 11, 2011 event, in one of those bays, the run up reached over 40 m. The pictures of devastated areas provided by NOAA are of a clear message to the people with knowledge on tsunamis (NOAA Web Site for “2011/03/11 Tohoku Japan earthquake and tsunami”). During the next few hours and days, TV and newspaper reports confirmed the very large magnitude of the disaster. In fact, of the near 20,000 mortal victims, most of them lost their lives due to the tsunami and the material losses were caused mostly by the tsunami generated by the 2011 Great East Japan earthquake.

Because of the strategic location of the Hawaiian Island, almost at the center of the Pacific Ocean, the Pacific Tsunami Warning Center (e.g., PTWC Web Site) is located in Ewa Beach at Hawaii Head and is operated by NOAA. It was initially installed in 1949 when the Aleutian Alaska Islands earthquake generated a tsunami that killed 165 persons in Hawaii in 1946 (e.g., USC Tsunami Research Group Web Site). As the sea recessed, people invaded the dry sea bed, and when the second wave arrived those people lost their lives. Also during the tsunami attacked Camaná, Peru caused by the 2001 Arequipa, Peru earthquake (e.g., International Tsunami Survey Team, 2001), some 70 people walked down on the dry sea bottom and were killed by the second wave; unfortunately they did not know what had happened in Hawaii in 1946. After the tsunami caused by the 1960 Valdivia, Chile earthquake, the PTWC incorporated as members all countries located in the Pacific Ocean. Following the Indian Ocean Tsunami of 2004, at present there is a Tsunami Warning System for the Indian Ocean where UNESCO and the USAID played key roles (International Oceanographic Commission Web Site).

The 1985 Algarrobo, Chile earthquake left valuable information on the local physical characteristics, the soil´s influence and its geographic distribution on the seismic intensity and thus on the damage degree. The Maule, Chile earthquake (February 27, 2010, Mw 8.8), had a death toll of 709 persons but the material losses were some US$ 30, 000 million, most of the losses being from damage to non-structural elements and buildings contents. The damage to hospital facilities was nearly US$ 3,000 million, and 79 hospitals were put out of service. Chile needed some 10 field hospitals provided by friendly countries (United Nations, 2010). The large magnitude and duration of the event gradually increased the pore water pressure and when it surpassed the confining vertical load, soil liquefaction occurred extensively, even a few hundred kilometers from the seismic epicenter.

Liquefaction also occurred during the 2011 Great East Japan earthquake. Extensive soil liquefaction occurred along the shore of Tokyo Bay and along the banks of Tone river located at north of Tokyo that discharge the water into the Pacific Ocean (EERI, 2013). During both earthquakes, i.e, the 2010 in Chile and the 2011 in Japan, one of the most damaging effects was soil liquefaction and lateral spreading.

During the Great East Japan Earthquake a number of high-rise buildings protected with seismic isolations and energy dissipation devices behaved adequately in response to high seismic intensity. In Sendai city where the seismic intensity reached X in the Mercalli Modified Intensity Scale (MMI), buildings protected by energy reducing device, did not suffered any damage as for example the Sendai First Tower, 24 story high building + 2 penthouses and 2 basements, and the Sendai MT a 30 story high building. More advanced equipment were also installed in a few buildings which generate forces contrary to that produced by the seismic reaction of inertial forces. In Chile some buildings were protected by seismic isolation and energy dissipation devices and responded as expected.

2.3. Colombia

The Colombian Nevado del Ruiz volcanic eruption on November 13, 1985, killed 23,000 of its 30,000 total inhabitants of Armero city (e.g., Wright and Pierson, 1992). The United Nations Disaster Relief Office in Geneva (UNDRO) under the leadership of volcanologist Dr. John Tomblin, who was providing technical assistance to Colombia’s INGEOMINAS, warned the department of Tolima and the city of Armero authorities at the end of October 1985 that the eruption was imminent as the lava flow was approaching the volcano crater. Working closely together with INGEOMINAS, the official institution of the Government of Colombia dealing with geology and mines, they provided the lahar hazard map of Armero (Fig. 1; Kuroiwa, 2004). The Lagunillas river crosses Armero at its center from west to east, that heads on to Nevado del Ruiz strato-volcano 5,400 m above sea level (a.s.l.), covered with 30 m of ice cap, which is located west of Armero. During the eruption of volcano on November 13, 1985, it melted the ice cap and an enormous volume of mud, lava and ice flowed down toward Armero along the Lagunilla River. A previous landslide had dammed a large volume of water, so the volume of lahar was substantially increased. When people of Armero heared tremendous noise of the lahar, they tried to evacuate the city in panic, so the evacuation resulted in chaos. Many of them lost their lives hit by cars. But it was too late. The governor of the department of Tolima was put into jail, but not the local authorities of Armero. They were buried under 3-4 m of mud, ice and large rocks. (Personal communications with survivor of the Armero disaster, January 1986, and with Dr. John Tomblin, 1985). In January 1986, the author inspected the remains of Armero which had been razed (Fig.2b). Less than 20% of the city, the north and south ends, was practically intact. Comparing the lahar hazard map of Armero provided by INGEOMINAS/UNDRO with the actual effects, it was remarkably precise (Fig. 1). The refuge area east of Armero consisted of gently sloping hills, easy to climb by children and aged persons (Fig. 2b). A comment on the Armero tragic disaster is included in Box 4.1, p 204 of the book “Disaster Reduction”, presented during the UN World Conference on Disaster Reduction held in Kobe, Hyogo, Japan in January 2005 (i.e., Kuroiwa, 2004). The tragic lesson was learned very well in Colombia and was applied in the quick and efficient rehabilitation and reconstruction of the city of Armenia affected by the 1999 January 25 Armenia, Colombia earthquake. The death toll was about 1,000, and 4,000 were injured and over 200,000 were left homeless. The damage distribution map was unusual. There were some strips where practically no damage occurred at all, but in some other strips the damage to brick construction was 100%, as in the Brasilia quarter of Armenia City. When the area

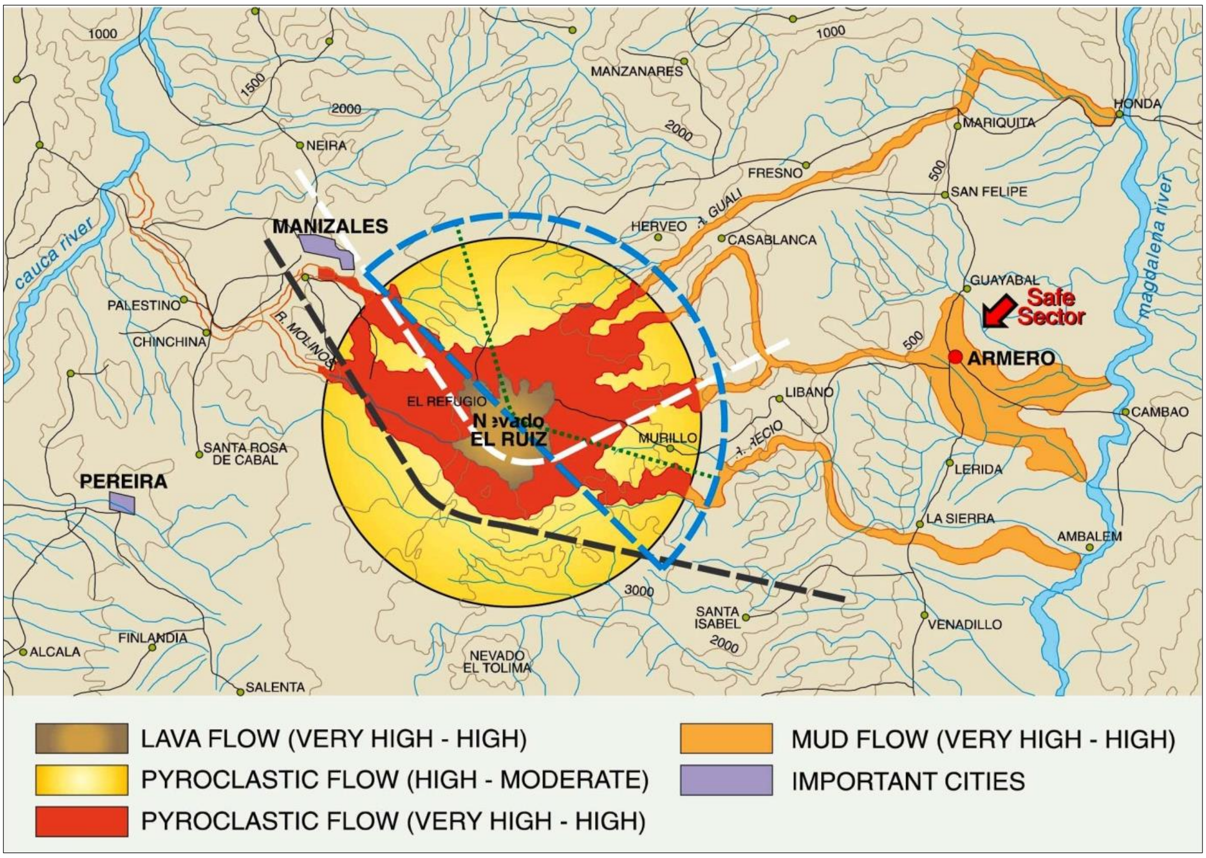


Fig. 1. Lahar hazard map of Armero (UNDRO/INGEOMINAS) provided to the author by Dr. John Tomblin from UNDRO, at Geneve in November, 1985. Note the safe sector east of Armero. After Kuroiwa (2004)

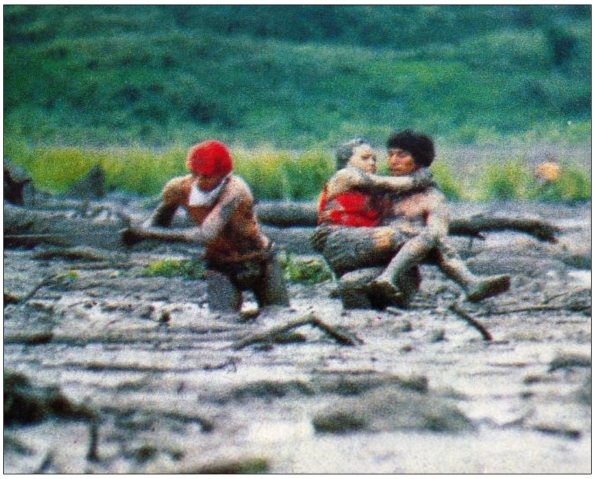


Fig. 2a. People being rescued from mud flow in Armero. In the background, there is the safe sector of Fig.1 east of the city easy to climb by children and aged people. Photo provided by UNDRO to the author. After Kuroiwa (2004)

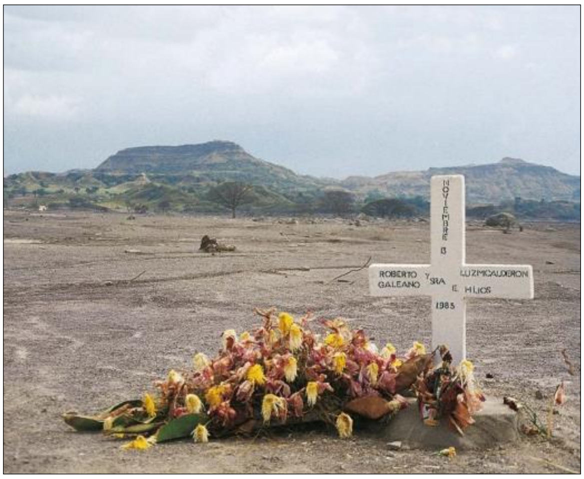


Fig. 2b. Downtown Armero where thousands of people resided before the volcanic disaster. Photo taken by the author in January 1986.

was being prepared for urban use, a large volume of soil was cut and the depressions were filled with not much care. Previous settlements and the large intensity generated in the filled soil were responsible for the total destruction of constructions there. During the 2001 Arequipa, Peru earthquake, in the northern sector of the city of Tacna the plotted damage also clearly showed the areas that were filled and the seismic damage was almost total there according to a report from the Regional Office in Tacna of the Ministry of Construction, Housing and Sanitation (MVCS).

2.4. Venezuela

The 1999 Venezuela debris flow and flash flood disaster of 1999 have a return period of about a century, so hazardous alluvial fans were occupied during the second half of the 20th century, by highly developed urban conglomerates in the Venezuelan Caribbean, north of Caracas, the country's capital city. There, from December 14 to 16, 1999, a major storm deposited 911 mm of rain centered on the Venezuelan state of Vargas. Two weeks previously, that area had been affected by a 200 mm rainfall, so the area was wet, and when the disaster occurred the water emission was quick. The death toll was some 15,000 persons, and the total material losses are uncertain, but the best estimation may be nearly US$ 10,000 million; however, there are discrepancies depending on the institution preparing the reports, (e.g., Larsen et al., 2001; Munich Re, 2004).

The constructions included dozens of R. C. multistory apartment buildings; however most of the residences -summer and weekend resorts- were one- and two-story masonry dwellings. This highly vulnerable built-up area, was a scenario ready for disasters (Larsen et al., 2001). The Venezuela Civil Protection invited the author for lecturing in two international seminars in Caracas. During the first visit, inspection was made from helicopter, and during the second visit inspection was made by visiting the reconstruction works underway. The results were presented in a Sabo International Seminar in Toyama city, Japan (Kuroiwa, 2010). The author expresses his gratitude to the Government of Venezuela, the Prefecture of Toyama and JICA.

2.5. Peru

The Lima Metropolitan area at present houses some 9.5 million people; the awareness of most of these people that they face disaster is very low. The last destructive earthquake struck the area in 1974. The M 7.8 earthquake had a death toll of 252 persons. That was more than 40 years ago, so the great majority of people living in Lima have no any direct experience of a destructive earthquake. They are not interested in protecting themselves and their properties from a destructive earthquake and tsunami. Most of them think "Nothing will happen. It is not my problem." However, two cooperative investigations had been conducted. The first one "Preparation in case of Earthquake and for Tsunami Disaster and Early Recovery of Lima and Callao" funded by the European Commission's Humanitarian Aid and Civil Protection Department (ECHO), were conducted by UNDP/Peru. This project concluded that there was a "high probability of occurrence of a large magnitude earthquake and tsunami affecting the Lima /Callao area." The focus of this project is to reduce the suffering of Limeños (the inhabitants of Lima) if the assumed disaster occurs, providing humanitarian assistance, recovering the functioning of the lifeline services such as water, energy, transportation and communication, as soon as possible.

The second was the Project on "Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru a Japan-Peru cooperative investigation partnership for sustainable development" under SATREPS scheme (Yamasaki and Zavala, 2013) that has conducted comprehensive research studies on earthquake and tsunami disaster mitigation in Peru developed during 2008-2013. The important and useful data to reduce disasters in Metropolitan Lima are included in 12 papers in the special issue of the Journal of Disaster Research Vol. 8 N° 2, March 2013. The main conclusion of the SETREPS report is that if a large magnitude earthquake accompanied by a tsunami occurs in the subduction zone near to Lima, in the Metropolitan area the death toll may be some tens of thousands of victims and the material losses could be huge.

According to the Inter-American Development Bank (2013), Peru has US$ 450,000 million at risk in a disaster of natural origin. The author is assuming a loss of 8% at risk, then the losses would be some US$ 36,000 million. This is a task that all Peruvians need to face, if the country is attempting to be a first world country in the next few decades. The announcement was made when the Inter-American Bank provided Peru with a loan of US$ 300 million early in 2014 for disaster contingencies. The Government of Japan has also provided Peru with a contingency loan for a similar amount.

The results of these two investigations are complementary: the Japan-Peru project estimated the impact of large earthquake and tsunami and the ECHO/UNDP focused on what to do to reduce the suffering of the inhabitants of Lima and what to do for a rapid recovery. It is necessary that the results of those two investigations motivate people of all ages and social classes, which is not easy because of the lack of knowledge on earthquakes and tsunamis. The author has been requesting for decades that disaster risk management be a State Policy in Peru. The 2010 Maule, Chile earthquake with losses of US$ 30,000 million prompted the Peruvian Government and civil society to approve unanimously in the Palace of Government on December 17, 2010, that Peru's 32nd State Policy is Disaster Risk Management. Two of the important considerations are that education for reducing disaster is compulsory for all levels of education and that cities be expanded and densified according to the environment, i.e., using multihazard maps. Following El Niño 1997-98 at the end of 1998, the author proposed to the Peruvian Prime Minister, who was at the same time Head of the El Niño Reconstruction Committee (CEREN) that the reconstruction of the northwestern cities seriously affected by El Niño 1997-98 be based on multihazard maps. The best argument to convince authorities from central and local was that the flooding maps of the main cities in Peru's north-western region affected by El Niño 1997-98 were practically carbon copies of those flooding maps affected by El Niño 1982-83. Both El Niño Phenomena were high-grade extraordinary events.

From 1998 to 2012 under the frame of Peru's Sustainable Cities Programme, the multihazard maps of 175 Peruvian cities with 7.5 million inhabitants were developed, including the land-use planning to reduce disasters and including 4 to 8 disaster mitigation profiles for each city.

Peru's Civil Defense (INDECI) and the Peruvian Engineers Association (Colegio de Ingenieros del Perú (CIP)) with a membership of more than 150,000 engineers of all specialties will provide technical advice to local authorities of cities spread all over the country so that in the year 2021, bicentennial of the country's independence, Peruvian cities will be physically safer than at present (Kuroiwa, 2014).

3. LATEST ADVANCEMENTS IN SCIENCE AND TECHNOLOGY TO REDUCE DISASTERS - SOME APPLICATIONS IN ENGINEERING PRACTICE

Only a few years ago it was not possible to estimate the tsunami run-up for a return period of 1,000 years in the subduction zone off the west coast of South America where the Nazca and South America plates interact, necessary data for the design of buildings and infrastructure in tsunami inundation zones, because of the lack of historical data. A tsunami is considered to be an infrequent event. For example, in the Indian Ocean the only tsunami that occurred during the 20th century and early 21st century was the Great Indian Ocean Tsunami of December 26, 2004. On the central west coast of Peru where Lima, the country´s capital city and its nearby seaport of Callao are located, historical data on earthquakes and tsunamis that have struck the area exist only since the 16th century when the Spaniards arrived in South America.

The information collected by chroniclers and religious is kept in "Archivo General de Indias" in Seville, Spain (Centro Virtual Cervantes Web Site). It was created by the king Charles III in 1785, with the objective to centralize in only one place all the documents of the Spain colonies. The Archive has 43,000 files with 80 million page, 8,000 maps and drawings, prepared by the metropolitan administration for example by the Viceroyalty of Peru. It is the main source of data for South American seismologists and historians. After the independence of the South American countries, local historians continued to collect data, starting about 200 years ago. Since the early decades of the 20th century, when earthquakes started to be recorded instrumentally, the number of seismic events has increased exponentially. The data available are applied to find the seismicity of a region using the theory of probabilities to determine, for example, the peak acceleration for earthquakes with a period of 500 years, which most of the seismic codes consider for designing buildings, as does the present Peruvian Seismic Code NTE. 0.30 of 2006 which applied the seismic catalog of IGP. The existing data are also useful for finding the seismic peak acceleration for a return period of 1,000 and 2,000 years, as required, for example, by the American Association of State Highway and Transportation Officials (AASHTO), and used by most countries in the Americas to support quality and safety in designing and executing the construction of transportation projects. Such infrastructure is critical in the event of disaster: if highways, bridges and tunnels show consequences of failures, this could be fatal in post-disaster activities, such as supplying humanitarian aid and undertaking rehabilitation and reconstruction.

But this is not the case for tsunamis on the west coast of South America where the existing data from the last 500 years include very little information on tsunamis, insufficient to apply the probabilistic approach to an estimated tsunami return period for practical engineering application.

In the case of Peru, for example, a large number of earthquakes of magnitude 4 and over have occurred all over the country, but only those generated in the subduction zone with a magnitude of some 7 and over, and with a focal depth of less than 40-60 km, are able to generate tsunamis, so the number of destructive tsunamis which have affected the Peruvian coast in the past five centuries is very small. The most destructive earthquake and tsunami that struck Peru's central coast where Lima, the country's capital city and its nearby seaport of Callao are located, occurred on October 28, 1746 with Magnitude 8.4 (Silgado, 1974) or some Mw 8.7-8.8 estimated by other seismologists. Jimenez et al. (2013) using macroseismic historical data of the October 28, 1746 Callao, Peru earthquake and forward fitting approach, reconstructed the coseismic displacement that caused the associated tsunami. The determined model is consist of a length 550 km parallel to the coast line, a width of 140 km and the mean slip 11.5 m at depth 8.0 km. It is assumed to be an event with a return period of 1,000 years, as was the Great East Japan earthquake and tsunami of March 11, 2011. The Pacific Plate and the North American Plate where east Honshu is located, and the more active segments where the Nazca Plate and the South American Plate interact, are approaching each other at a rate of 7-9 cm/year; so historical data of earthquakes and tsunamis that have occurred in those subduction zones might be used to "check" or compare the result of modeling of the coseismic displacements of the 1746 earthquake and tsunami, including the resulting tsunami height in the three virtual tidal gauges, two located strategically in Callao, and one below the Lima cliff, in Miraflores, located 80 m.a.s.l.

Fig. 3 shows the tsunami inundation map of the shore of Lima and Callao with the location of the three virtual gauges and Fig. 4 the simulated tsunami waves for these three key locations. See Jimenez et al. (2013) for more detailed information.

At the tidal gauge at DHN located few hundred meters east-south east of the port of Callao, the first wave had a height of 10 m when it arrived there 23 minutes after the earthquake. At La Punta, Callao, where the Peruvian Navy Academy is located, the height of the first tsunami wave was some 9.6 m, and at the foot of the Costa Verde cliff, the height of the first tsunami wave was 22.0 m. These data are very useful for engineering application; however, they need to be applied carefully: according to one of the members of the research team (personal communication with Erick Mas, 2014), for more precise results it is necessary to improve the bathymetry data of the sea bottom where the ideal tsunami propagates, using TUNAMI the programme developed by Imamura (1999) of Tohoku University.

One of the most interesting locations from the practical point of view is the run-up at the present location of the Callao seaport. The last station of subway Line 2, at present under construction, is located only some 400 m from the coastal line, and it will most probably be flooded by a tsunami with a 500 and 1,000 years return period. According to the best available data, the tsunami height there in 1746 was some 7 m., since a few people saved their lives by staying on top of the wall that surrounded Callao at that time; and where the viceroy Manzo de Velazco founded the new Callao, in the present district of Bellavista, with a monument near the corner of Av. Grau and Colina Street. The development of the port of Callao has substantially modified the hydraulics of the port, with the construction of sea walls to permit ocean going ships' operations.

According to the latest available data (Silgado, 1974), for the 1746 Callao, Peru earthquake the magnitude was estimated 8.4 equivalent to Mw 8.7-8.8 (personal communication with Dr. Hernando Tavera from IGP). This indicates that the 1746 earthquake and tsunami might have a return period of 500 years, and by assuming geometry of the fault 550 km long and 140 wide, it may be an event of Mw

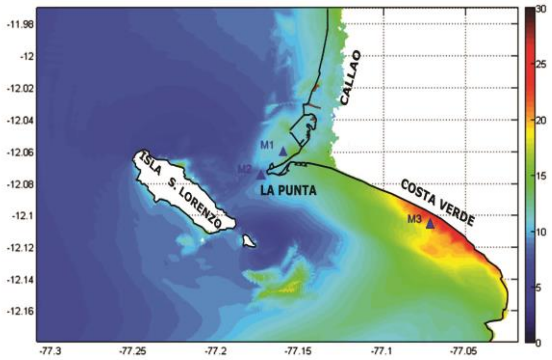


Fig. 3. Inundation map of Lima and the location of three virtual tidal gauges. Courtesy of Dr. Cesar Jimenez.

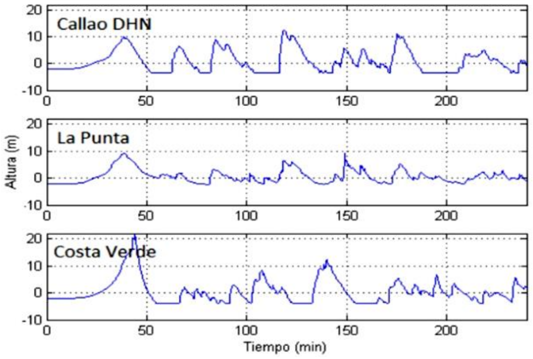


Fig. 4. Simulated tsunami waves. Courtesy of Dr. Cesar Jimenez.

9.0 with 1,000 years return period, as was the 2011 Great East Japan earthquake. The inundation map of Jimenez et al. (2013) is also useful for taking engineering protection measures for the new second landing strip of the Jorge Chavez Lima-Callao International Airport, which is located north-west and only a few hundred meters from the coastal line and which will most probably be flooded by tsunamis of 500 and 1,000 years return period.

The tunnel under landing strip Nº 2 of the International Airport of Lima, which is under construction at present, is located 1.3 km from the coastal line and might be flooded by a tsunami with a return period of 1,000 years; and so the new tunnel and bridge have been designed with an earthquake of 1,000 years return period, but promising the construction of masonry housing west of the Gambetta Avenue up to near the border to reduce the destruction the tsunami may cause as well as to reduce its reaches on land. However, this structural measure needs to be complemented with non- structural measures to protect people living in the inundation area as well as the users of the tunnel under the new runway N° 2 of Lima International Airport. The tunnel is not expected to suffer structural damage. The driver has some 20 minutes to abandon the tunnel and no vehicles must be not permitted to enter into the tunnel in the event of a large magnitude earthquake. Accesses to the tunnel need to be restricted.

4. PERU CASE AS RECIPIENT OF THE BENEFITS OF INTERNATIONAL COOPERATION

There are various reasons for selecting Peru as a study case of the benefits received from international cooperation. Peru and Mexico were selected by the Government of Japan to spread the high Japanese technology in Earthquake Engineering in South America and Central America, respectively, using, for example, Third Country Seminars. The Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation - CISMID began its activities in 1986; and in Mexico CENAPRED started up soon after. Peru and Indonesia are the two countries with the largest number of participants at the IISEE during its more than 50 years of continuous profitable activities.

Following the 1970 Ancash, Peru earthquake with a death toll of 67,000, which was the disaster with the highest death toll in the Americas in the 20th century (USGS Web Site-6), Peru had priority for the technical assistance from Japan. For example, two months after the Ancash disaster a Japanese Scientific Mission came to Peru, headed by the Prof. Ryohei Morimoto, who was at the time the director of the Earthquake Research Institute of the University of Tokyo.

Maybe the best way to show the impact of the international technical assistance is describing some of the products developed in Peru based on those cooperative activities. The most significant products may be:

- Sustainable Cities Programme 1998-2012 and its complementary activities for the period 2014-2021.
- Development of confined masonry seismic resistant construction done in Chimbote from 1970 to

1974, and.

- Design and construction of seismic resistant buildings and infrastructures, focusing on school buildings.

4.1. Sustainable Cities Programme in Peru

The development of the Sustainable Cities Programme is focused on its first attribute: the city´s physical safety. The other attributes of a sustainable city as defined in Peru are: orderly, healthy, culturally and physically attractive, efficient functioning and development without having negative impact on the environment and cultural/historic heritage sites, governable and competitive (Kuroiwa, 2014, specifically in the Second chapter: Sustainable City Agenda for the 21st Century; UN-HABITAT).

The physical safety of cities is provided by planning the cities based on their multihazard map which includes all natural intense events and negative human activities threatening the cities built up areas, including the foreseen expansion areas. Then the cities are expanded and densified in sectors with low and medium hazards. The sector with high hazard is used, if a detailed site investigation shows that it is economically feasible. Sectors with very high hazard are not permitted for urban uses.

The Japanese Scientific Mission of 1970 consisted of top researchers from the Earthquake Research Institute of the University of Tokyo including a geologist and an earthquake engineer, headed by the director Prof. Ryohei Morimoto, a geologist. The mission also included an expert on geotechnical engineering from BRI, MLIT. This mission stayed in Peru for as unusually long time, four months. Two of Peruvian counterparts were former participants of the IISEE, seismologist at the IGP, and a civil structural engineer from National University of Engineering (UNI: Universidad Nacional de Ingenieria, Peru). So what it was learnt theoretically in Japan was put into practice at the full scale laboratory, that was the city of Chimbote, affected by the May 31st 1970 Ancash, Peru earthquake.

During the Individual Earthquake Engineering course (1974-75) at the IISEE one of the topic was the requirement for a nuclear reactor site of the UN International Atomic Energy Agencies (IAEA) sited in Vienna, Austria. The professor Makoto Watabe provided the necessary information and organized a field trip to Tokai-mura Nuclear Power Plant where four reactors were functioning, and two high pressure models were under construction. That was the tools used to investigate the site characteristic of a small nuclear research reactor in Huarangal, located some 35 km north-east of Lima. The state of the art for developing multihazard maps was reached in Peru during the 1970s and 1980s thanks to Japanese technical assistance.

In order to have wider use of multihazard maps, the method was simplified reducing operation costs and data processing, and this method was used to develop the hazard maps of 175 cities participating in the Peruvian Sustainable Cities Programme (SCP) 1998-2012 (Kuroiwa, 2014; UN-HABITAT).

By comparing the UN-INDECI Regional Seismic Scenario 1992-95 in south-west Peru with the real effects of the June 23, 2001 Arequipa, Peru earthquake, and also the hazard maps of Ica, Pisco, Chincha, Tambo de Mora and Cañete developed in 2001-02, six years before the 15 August 2007 Pisco Peru event, they proved that the multihazard maps are very useful for developing safe cities, expanding and densifying in sector with low and medium hazards locating large industrial plants, selecting the location of essential facilities in the event of disasters, such as hospitals, school buildings, emergency operation centers, and for designing, lifeline services such as water, energy, transportation and communications.

Fig. 5 shows the Pisco multihazard map developed in 2001-02 under the frame of SCP. As may be observed all the damage occurred in sectors with very high hazard (in red) and high hazard (orange). The red sector is threatened by tsunami and soil liquefaction as really happened during the earthquake. In Fig. 6 (5) it is possible to observe fishing boats landed in San Andres.

In Fig. 6, (1) shows liquefaction and lateral spread of the Panamerican Highway approaching the bridge from south to north, that crosses the Pisco river in its lower part, so it is always humid. Fig. 6 (2) shows the damage to water and sewage pipes due to the soil high seismic intensity VIII (MMI) and large soil deformations. The soil there consists of fine sand and silt with the water table near the surface.

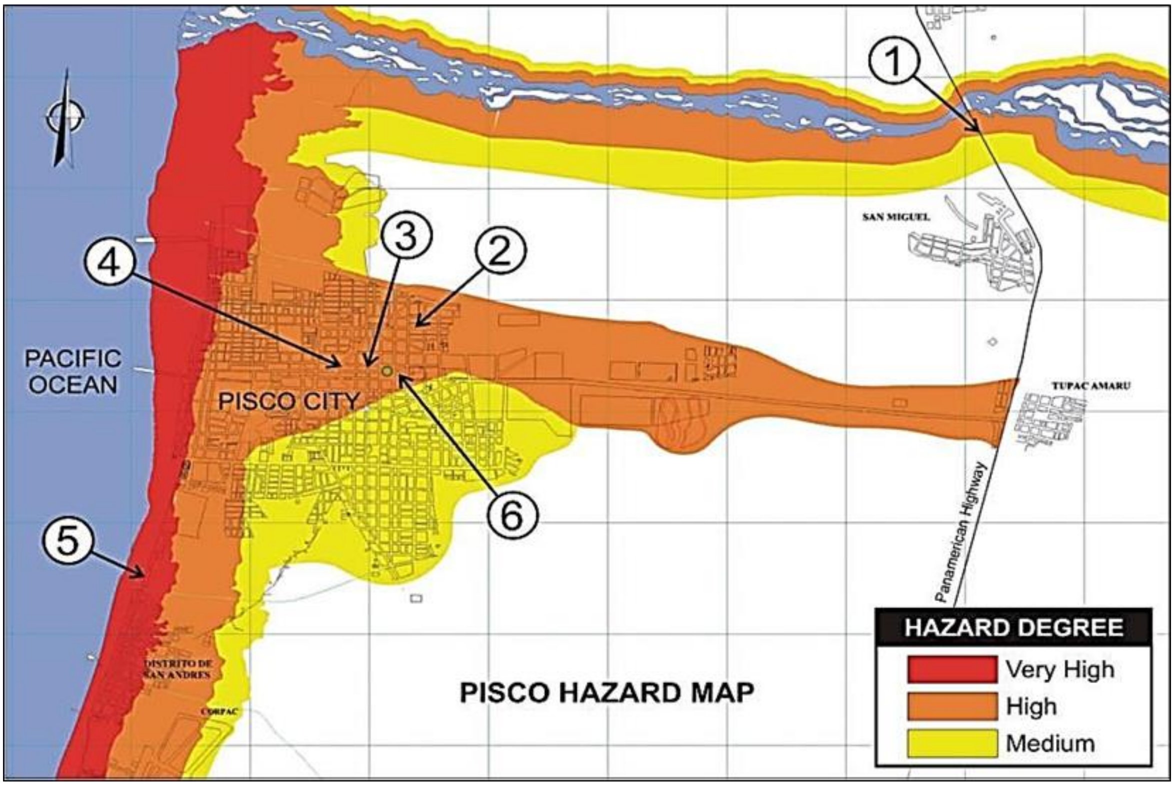


Fig. 5. Multihazard map of Pisco developed during 2001-2002 under the frame of Peru Sustainable City Programme (INDECI/UNDP). Courtesy of INDECI.

Fig. 6. Effect of the Pisco earthquake of August 15, 2007. All photos taken by the author, except picture (5) taken by the Peru Air Force and provided to the author by INDECI.

Figs. 6 (3), (4) and (6) show the collapse of two R. C. building without seismic-resistant design, and the church of Pisco with adobe walls and its roof collapsed over members of families of some 85 persons, who perished. Fig. 6 (5) shows small fishing boats that landed in San Andres, artisanal fishing port. The tsunami wave high and inundation limit agreed with the estimation made 6 years before the 2007 earthquake and tsunami.

The hazard map of the locality of Tambo de Mora was developed in 2001-2002 as part of the hazard map of the city of Chincha, the provincial capital. Fig. 7 (1) shows the typical volcano of soil liquefaction that extensively occurred there. Fig. 7 (2) shows the lateral spread of a wall at the Tambo de Mora jail. The initial clearance between two walls was only 2.5 cm (one inch). The brick house of Fig. 7 (3) and the Jail of Tambo de Mora Fig. 7 (4), both settled 0.55 m.

Figs. 7 (5) and (6) show high adobe walls with no reinforcement of a church, 4.2 m high walls and a deposit with it walls of 2.8 m high, and no roof. Both adobe constructions had no damage at all.

Why were the microzonation effects so clear in Tambo de Mora?. The lower sector of Tambo de Mora consists of fine sand and silt water saturated soil and extensive liquefaction occurred as predicted six years prior to the earthquake. The seismic intensity there was IX MMI.

The adobe constructions are built on top of a small hill that was cut, to have flat area as seen in Fig. 7 (5) and Fig. 8. Soil at that level is very dry and compact. The intensity there was less than VI MMI.

Fig. 7. Microzonation effects in Tambo de Mora and photos taken in August, 2007 after the Earthquake of August 15, 2007. (1) Volcano of soil liquefaction. (2) Lateral spreading, a “door was opened”. (3) Settlement of 0.80m 1.00m. (4) Settlement of bearing walls and broken concrete floor. (5) Undamaged adobe church. (6) Adobe fence, only 200 m from the Tambo de Mora main square (Plaza de Armas) where soil liquefaction occurred. 7) Large and abundant cracks were opened north of Tambo de Mora where also a 3 km long and 0.6 km wide block was displaced a few meters toward the ocean. Microzonation map is a courtesy of INDESI. All photos are taken by the author.

Fig. 8. Microzonation effects in a 50 m long street in Tambo de Mora. Photo taken by the author, December 2013.

Fig. 8 was taken a year ago, showing the church (1) with no damage (2) is a one story high brick construction with severe damage, and the brick house (3) settled some 0.40 m. From (1) to (3) there are some 40m. Notice that the change of slope of the street level, mark the limit between the low fine grain water saturated soil and the very dry and compact soil.

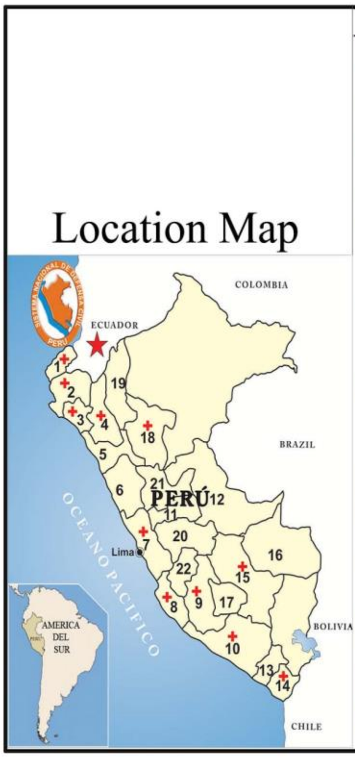
The SCP of INDECI/UNDP was financed continuously by the Peruvian Prime Minister´s Office during 1998-2012, however the results were not as expected, because of lack of administrative capacity of the local authorities and the necessary financing. However now, the Ministry of Economy and Finance (MEF) depending on the results, is providing rotative funding. From 1998 to 2012, the hazard maps, land use planning for 175 Peruvian cities, together with 4 to 8 disaster mitigation profile projects were developed as shown in Table 1.

During COP 20, i.e., the United Nations Conference on Climatic Change, developed in Lima Peru, from December 1 to 12, 2014, in a special presentation of the Sustainable Programme Cities by the Peru Civil Defense Institute (INDECI) and UNDP on December 5, 2014, up dated to 2014, reported that it have been produced 189 investigation of technical scientific nature, including reviewing of some of the investigations, trying to protect 8,300,000 inhabitants and cities of Ecuador included in the joint program are: Huayquillas (50,000), Machada (218,000), Arenillas (20,000) and Macará (15,000). Note that the number in brackets is the inhabitants in each city, so the total population included are 303,000.

The Peruvian Association of Engineers (CIP: Colegio de Ingenieros del Peru) with over 150,000 members of all specialties with its regional branches, together with decentralized offices of Peru´s Civil Defense is going to provide technical assistance to the municipalities to complete the implementation of the SCP all over the country, so that by the year 2021, year of the bicentennial commemoration of Peru´s independence, Peruvian cities may be much safer that they are at present, to improve the life quality of their residents.

The SCP of INDECI/UNDP has received national and international recognition. In 2012 various UN agencies including UN-HABITAT, UNDP, the World Bank and the Organization of American States (OAS) called an open contest to present the most significant projects on disaster reduction. Out of 81 projects presented by Latin American and Caribbean countries, Peru´s Sustainable Cities Programme was selected as the best.

Table 1. The SCP was developed for 175 Peruvian cities from 1998 to 2012. Additionally four cities in Ecuador ★ were studied with the support of the Organization of American States. With the participation of professors and researchers of National Universities located in the regions +. Courtesy of INDECI. The author was the chief technical advisor of the Peru Sustainable Cities Programme 1998-2012 and formulated the action plan from 2014 to 2021.



Regions	Cities, showing population in thousands
1 TUMBES	- Tumbes (88.4*), Aguas Verdes (10.3), Zarumilla (22.5), Papayal (5.0).
2 PIURA	- Talara (135.0), Sullana (180.0), Paita (57.4), Sechura (16.7), Chulucanas (55.2), Huancabamba (6.8), Ayabaca (6.0), Castilla (115.0), Catacaos (64.3), Piura (450.4), Suyo (1.5).
3 LAMBAYEQUE	- Chiclayo (535.4), San José (7.59), Pimentel (14.2), Santa Rosa (13.0), Monsefú (24.6), Eten (11.9), Puerto Eten (2.5), Reque (9.7), Morrope (4.7), Túcume (6.7), Lambayeque (40.9), Ferreñafe (32.3), Olmos (36.6), Picsi (4.8).
4 CAJAMARCA	- Cajamarca (98.2), Baños del Inca (5.35), Jaén (54.7).
5 LA LIBERTAD	- Trujillo, Cercado de Trujillo, Florencia de Mora, Victor Larco, El Provenir, La Esperanza, (615.0), Pacasmayo (26.1), San Pedro de Lloc (12.2), Guadalupe (20.7), Huanchaco (44.8).
6 ANCASH	- Chimbote (313.2), Huarmey (17.1), Carhuaz (7.2), Recuay (3.1), Catac (2.6), Ticapampa (2.5), Huaraz (93.3), Caraz (11.3), Yungay (5.9), Ranrahirca (0.8).
7 LIMA	- San Vicente de Cañete (40.8), Cerro Azul (6.6), San Luis (11.7), Imperial (35.7), Nuevo Imperial (14.5), Lunahuaná (3.8), Quilmaná (12.5), Asia (14.1), Mala (22.8), San Antonio (3.4), Chancay (38.0) Huacho (63.2), Supe Puerto (12.4), Barranca (55.0), Paramonga (30.5), Chosica (145.5), Santa Eulalia (5.5), Ricardo Palma (3.9), Matucana (4.4), Laderas de San Juan de Lurigancho (8.0), Huaral (70.8), Huachipa (11.6).
8 ICA	- Ica (138.5), San José de los Molinos (2.9), La Tinguiña (30.1), Parcona (29.6), Subtanjalla (16.2), Guadalupe (8.3), Santiago (5.7), Los Aquijes (2.5), San Juan Bautista (0.9), Tate (2.0), Pueblo Nuevo (1.5), Palpa (8.2), Nazca (37.7), Chincha Baja, Tambo de Mora, Chincha Alta, Pueblo Nuevo, Sunampe, Grocio Prado, Alto Larán (143.8), Pisco y San Andrés (64.6).
9 AYACUCHO	- Ayacucho (107.4), Huanta (26.1).
10 AREQUIPA	- Arequipa (1,073), Cocachacra (6.6), Punta de Bombón (6.3) Dean Valdivia (4.9) Camaná (51.4), Chuquibamba (4.1), Caravelí (3.2), Aplao (3.5), Corire (2.1), Cosos (1.4), La Real (0.5), Huancarqui (1.4), Lara (2.9), Viraco (1.9), Pampacolca (2.7), Machaguay (0.6), Islay Pto Matarani (5.0) Mollendo (25.0), Huanca (1.5), Lluta (0.6), Callalli (1.8), Sibayo (0.8).
11 PASCO	- Oxapampa (14.2)
12 UCAYALI	- Pucallpa (272.6).
13 MOQUEGUA	- Omate (1.7), Puquina (1.5), Moquegua (36.0), Ilo (73.8).
14 TACNA	- Locumba (1.1) Cercado, Pocollay, Gregorio Albarracín, Ciudad Nueva y Alto Alianza (242.7), Tarata (4.7), Candarave (2.3).
15 CUSCO	- Cusco (256.0) Ollantaytambo (2.5), Urubamba (11.4), Calca (10.5), Pisac (2.6), Sicuani (37.1), Anta (16.3), Zurite (3.7), Lucre (3.9), Urcos (10.1), Limatambo (9.1) Taray (4.3), Santa Teresa (7.0), Machu Picchu(4.4).
16 MADRE DE DIOS	- Puerto Maldonado (35.2), Iberia (6.0), Iñapari (1.3).
17 APURIMAC	- Abancay (43.9).
18 SAN MARTIN	- Moyobamba (37.3), Tarapoto (87.9), Juanjuí (18.0), Bellavista (8.2), San Hilarión (3.0), Lamas (11.3), Nueva Cajamarca (15.8), Yuracyacu (3.8), Rioja (19.0).
19 AMAZONAS	- Chachapoyas (24.5).
20 JUNIN	- Huancayo (323.1), San Ramón (15.4).
21 HUANUCO	- Huánuco (149.2), Ambo (8.0)
22 HUANCAVELICA	- Huancavelica (41.3).

4.2. Confined Masonry Housing

The confined masonry construction method was developed from 1970 to 1974 in Chimbote city, seriously affected by the 1970 Ancash, Peru earthquake. It was developed by voluntary work of 25 graduate students from the Department of Civil Engineering of the National University of Engineering (FIC/UNI) who donated 700 months-men.

First, field inspections were made to estimate the extent of the task. The preliminary estimation was that some 5,000 houses needed retrofitting works. The main conclusion was that brick houses without R. C. columns and tie beams suffered severe damage or collapsed. Due to shape of the construction lot, 8 m wide and 20 m long, this resulted in a low wall density in the direction parallel to the main facade and high wall density in the walls perpendicular to the former. In the solutions were applied what had been learned in the field inspections, and two approaches that had been learned at the IISEE that the wall density is a good indicator of the house safety quality and that in Japan R. C. shear walls were considered to be very efficient for taking horizontal seismic forces.

Fig. 9 shows a typical retrofitting project in Chimbote. Notice that originally the house had only 4 columns located in its corners with acceptable wall density the “y” direction but low in the “x” direction: Each of the walls was drawn, including fissures and cracks, and classified in a few types. In case of cracks they were cleaned with air presence filled with mortal cement-sand, and steel meshes were fixed on top and again mortal was added. Notice the 7 new columns and two R.C. shear wall added in the “x” direction.

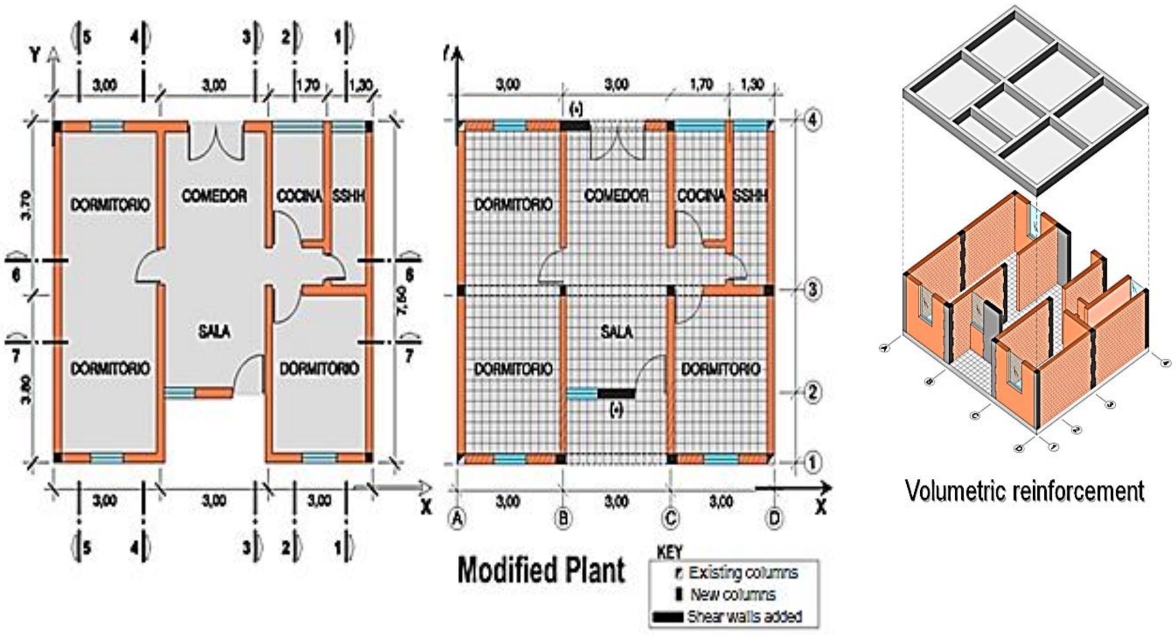
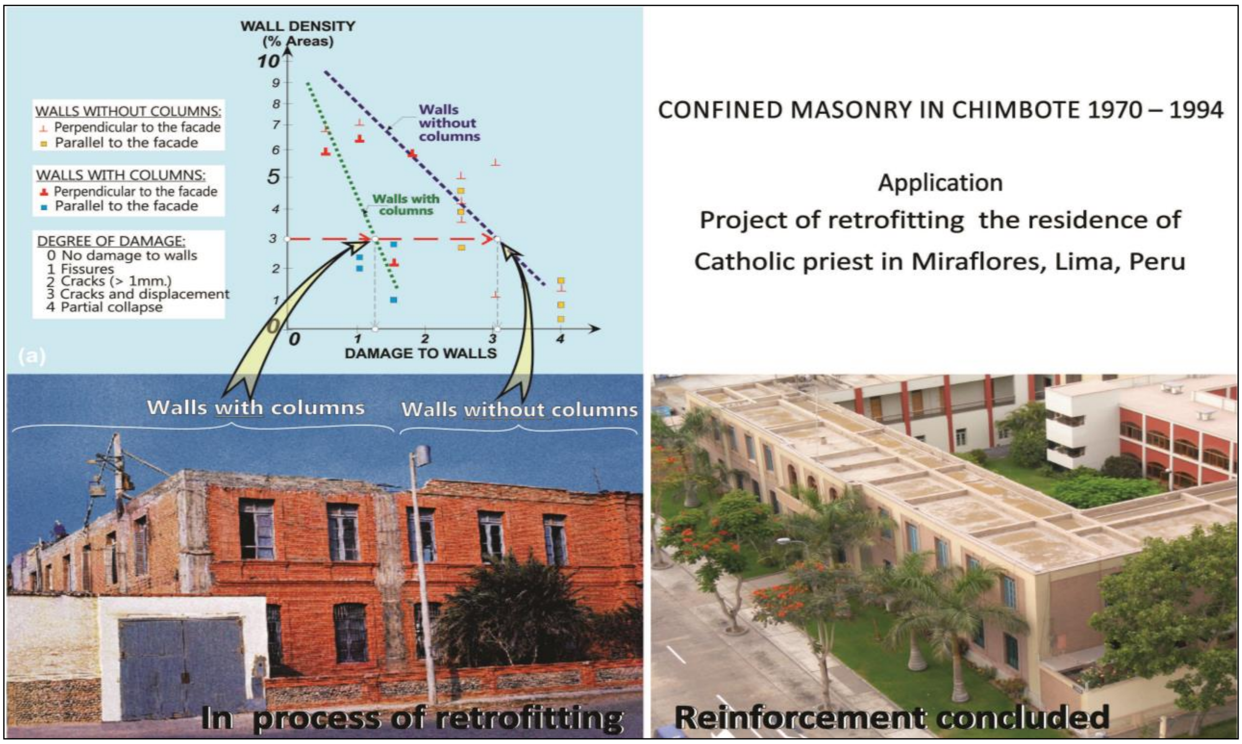


Fig. 9. A representative retrofitting project in Chimbote, 1970-1974, that was provided free to an affected family in Chimbote in 1972. Courtesy of FIC/UNI.


CONFINED MASONRY IN CHIMBOTE 1970 – 1994

Application

Project of retrofitting the residence of Catholic priest in Miraflores, Lima, Peru

Fig. 10. Two story brick building being converted into confined masonry. Courtesy of FIC/UNI.

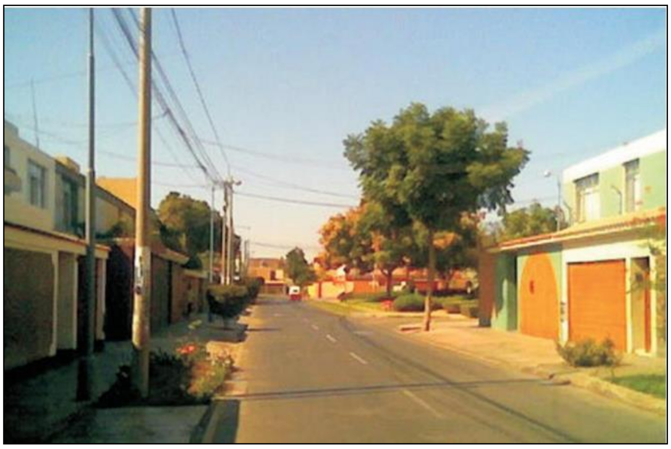


Fig. 11. Residential area of the city of Ica. Engineered confined masonry houses that did not suffer any damage during the August 15, 2007 earthquake. Photo taken by the author.

So Fig. 10 is the results of careful analysis of more than 2,500 brick houses for which were developed in detailed retrofitting and reinforcement projects, and some 1,000 brick houses that collapsed or suffered damage beyond the possibility of being recovered and a few that did not suffer any damage, so that Fig. 9 is the results of 3,500 investigated houses. It was applied in the residence of a Catholic priest located in Miraflores district, Lima Peru where R.C. columns have been added as well and inverted beam on the roof firmly connected in this two story residence. Applying Fig. 10 without column for wall density of 5%, the damage level is category 3, crack and partial displacement, but adding spatial system of R.C. column and tie beam the damage level is reduce to 1, small fissures. If that happens, by painting the walls, the fissures disappear, waiting for the next intense earthquake a few decades ahead.

Fig. 11 shows the engineered confined masonry houses that did not suffer any damage during the August 15, 2007 earthquake. The method was disseminated at UNI from 1975 and almost immediately in other Peruvian universities. So it is expected that engineered houses in Lima and other important cities, will not suffer significant damage in future earthquakes affecting the area.

4.3. Safe School Buildings

During the 1996 Nazca, Peru earthquake about 50% of R.C. buildings that suffered severe damage were

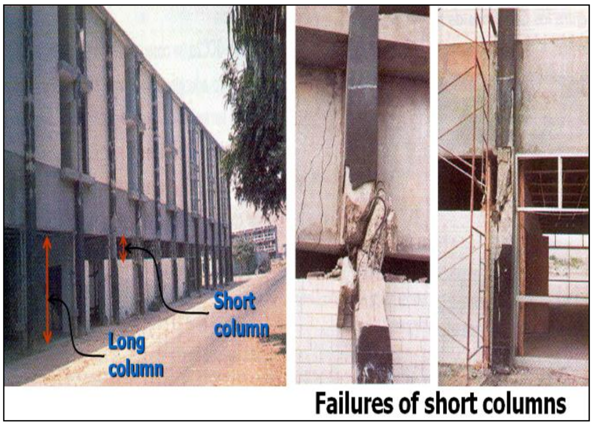


Fig. 12. Damage due to short column structural defect in Lima during the 1974 earthquake. Courtesy of National Police Academy in Lima, November 2007.

Fig. 13. Left block designed with Peru Seismic Code of 1977 and right building with the 1997 version. Photo taken by the author in Ica. September 2007.

Fig. 14. Safe Peruvian school building in the Arequipa Region, Peru. Photo taken by the author, June 2001.

school buildings, due to the structural defects of short columns, as also happened during the 1990 Luzon, Philippines earthquake and the 1999 Chi-Chi, Taiwan earthquake. The Peru Seismic Code of NTE 0.30 approved by MVCS in 1997 eliminated the short column structural defect by making two small changes to the previous 1977 seismic code. The permitted lateral drift was reduced from 0.010 to 0.007 and the importance factor was increased from U=1.3 to U= 1.5 as corresponds to essential facilities in the event of disaster. Fig. 12 shows the frequent failure due to short columns. Fig. 13 shows a school building at San José de Los Molinos in Ica affected by the August 15, 2007 Pisco, Peru earthquake. The left block was designed with the 1977 seismic code and the right one, designed with 1997 version. Fig. 14 shows a safe school building that instead of having short columns, has R. C. shear wall separated 2 cm from the filling walls. The back facade has the same design as the main one.

In Japan since early the 1920s rigid shear walls were regarded as highly resistant structural elements. In a very special lecture given by the Waseda University, Emeritus Professor Dr. Tachu Naito said at the Naito Commemorative Building (“Naito Kinen-Kan” in Japanese), early in 1962, that inspired in a ship traveling back from the USA, late in 1919 when a severe storm shook the ship violently at the Aleutian island, Alaska; the ship had, thin steel plates but so arranged horizontally and vertically that they controlled the entire ship from being deformed. Dr. Tachu Naito designed four rigid buildings with R.C. shear walls and rigid floors, which did not suffer damage during the Great Kanto earthquake in Japan, September 1, 1923 (e.g., Hammer, 2011), as for example the Bank of Japan and Kabuki Theater Building.

There are some other tools developed in Peru based on Japanese Earthquake Engineering; technology and also many other problems remain to be faced, such as the very vulnerable old adobe and quincha constructions located in severe tsunami inundation zones in Callao. Also the housing of the poor people living in slums around Lima in non-engineered brick dwellings without any reinforcement and located in zones of high natural hazard. Also in the next intense earthquake that is going to affect Lima, non-structural damage and building content will be important.

Fig. 15 shows non-structural damage and building contents in the Pisco Custom Office, a three story R. C. building, where the seismic intensity was VIII MMI during the 2007 Pisco earthquake.

In Lima in spite of the distance of over 200 km from the epicenter of the 2007 Pisco earthquake, Mw 8.0 USGS, there was important damage of those types in tall R. C. building, such as the SUNAT, the tax collecting institution, a 14 story building that suffered severe damage from the 5th to 14th story. Authorities were persuaded to relocate its computer center from the 9th story to the 3rd where the non-torsional vibrations and the lateral drift are acceptable.

Fig. 15. Three story R.C. Custom building in Pisco with non-structural damage and in its content. Photos kindly provided to the author by the administrator of Pisco Custom Office.

5. CONCLUDING REMARKS AND RECOMMENDATIONS

Since the January 2005 UN World Conference on Disaster Reduction held in Kobe, Hyogo, Japan, the results of the investigations of two extreme, unexpected disasters have become available: the Indian Ocean Tsunami Mw. 9.2 of December 26, 2004 with a death toll of some 230,000 persons, and the Great East Japan Earthquake and Tsunami, Mw. 9.0 of March 11, 2011 with total losses of over US$ 400,000 million including indemnification to communities contaminated by the nuclear accident of Fukushima Daiichi Nuclear Power Station. The studies of these two events have left very valuable lessons in science and technology, and their application to the engineering practice. The 2010 Maule, Chile Earthquake Mw 8.8, added important knowledge and experience. Also from the 1994 Northridge, the USA earthquake and the 1995 Kobe, Japan event, it has been possible to recover important lessons that in many aspects coincide with the results of the mega-events mentioned previously.

The main conclusions of those earthquakes and tsunamis may be summarized as follows.

1. Surface geology is critical in the seismic intensity, the damage caused to buildings and infrastructures, and the geographic distribution of the damage.
2. The 2004 Indian Ocean tsunami gave impulse to paleotsunami research in countries surrounding that ocean, in Japan and elsewhere.
3. The large amount of geophysical data recorded in north east Honshu, Japan one, of the world’s most densely instrumented regions, permitted the measurement of vertical and horizontal coseismic displacements. The data analyzed and interpreted results were considered to be among the world’s outstanding scientific advancements of the year 2011.
4. The results of 2 and 3 are allowing practical engineering application, such as finding the tsunami height for a return period of 1,000 years, impossible up to only very few years ago, e.g., on the west coast of South America, where the scarce historical data on tsunamis go back only 500 years.
5. In 1995 Kobe, Japan, the 2010 Maule, Chile and the 2011 Great East Japan earthquakes, those buildings designed with seismic codes of 1980-90 or newer, practically did not suffer structural seismic damage. In Peru, during the 2001 Arequipa, and the 2007 Pisco earthquakes, school buildings designed with the Peruvian Seismic Code NTE. 0.30 of 1997 did not suffer any damage. During the 1996 Nazca, Peru earthquake as well as during the 1990 Luzon, Philippines and the 1999 Chi-Chi, Taiwan earthquakes, damage in R. C. school buildings was about 50% of the total affected, due to the short column structural defect.
6. During the 2010 Maule, Chile, and even more clearly during the 2011 Great East Japan earthquakes,

seismic isolators and energy dissipation devices adequately protected buildings from high seismic intensity. There are a number of high-rise buildings in Sendai and Tokyo that did not suffer damage. In some areas in Sendai the seismic intensity reached X MMI.

7. During the 2010 Maule, Chile and the 2011 Great East Japan earthquake the damage due to soil liquefaction was very extensive even at distances of over 100 km from the seismic source: in Japan, along the Tokyo bay and rivers north of Tokyo that empty their water into the Pacific Ocean; in Chile, humid mining tails dams distant from the seismic source suffered severe damage. Soil liquefaction also occurred during the 2001 Arequipa, Peru earthquake, which is a very arid region. It clearly occurred on very humid soil as well during the 2007 Pisco, Peru earthquake.

   Soil liquefaction is a matter that needs to be technically considered to reduce losses, as soil liquefaction is one of the main reasons for losses occurred in the 2011 Great East Japan and in the 2010 Maule, Chile earthquakes.
8. During the 1995 Kobe, Japan earthquake, severe damage was caused to non-structural building elements and their contents. For example in hospitals, on average, damage to structural elements was only 8 % of the total losses, and damage to non-structural elements and building contents was 92 % because medical equipment is expensive. In the 2010 Maule, Chile and the 2011 Great East Japan earthquakes, damage to non-structural building components and building contents represented a very high percentage of the building's total losses. In Chile, progress is being made to protect those building components and contents. In Peru such protection has been provided in a very few cases. For example in a 14-story public building in Peru, severe torsional vibration above the fifth story caused the computer center located on the ninth story to suffer severe damage, so the computer center was relocated to the third story, where there was no torsional vibration and the lateral drift is acceptable.
9. The 2004 Indian Ocean Tsunami and the 2011 Great East Japan tsunami have shown again that bathymetry and topography have an important influence on the tsunami wave height, the direction of attack, and foundation scouring which depend also on the soil type and whether it has grass and trees. So if the tsunami effects on land are included in the multihazard map, and this is used for safe city planning, the damage from future tsunamis might be substantially reduced. In Peru an MSc. CE thesis developed at the National University of Engineering (i.e., Condori, 2014) has determined the tsunami effects on buildings, finding the water pressure on columns and shear walls. It is expected that by middle of 2016, Peru might have a draft for tsunami-resistant buildings, thanks to the support of Servicio Nacional de Capacitación para la Industria de Construcción (SENCICO), the building code regulation institutional arm of the Peruvian Ministry of Housing, Construction, and Sanitation (MVCS).
10. It is assumed that if R. C. or steel buildings are designed with the current seismic code and they are also made tsunami-resistant, and adequately located in tsunami inundation zones, the higher levels of high-rise buildings may be used as refuges with vertical evacuation. For elderly persons and small children unable to evacuate quickly, this is a matter of life or death, for example in La Punta located in a long narrow peninsula only 3 to 4 m a.s.l.
11. At present there are a number of useful tools to reduce disaster as a part of DRM developed in scientifically and technically advanced countries like Japan and the USA. But the problem is how to transfer their benefits to the main end users, the poor people living in disaster-prone Third World countries. Such countries need efficient intermediate steps, such as university graduate school, for them to train school teachers, because teachers are part of the communities where they live and work and they can reach the poor of the present and future generations for a better quality of life. Admittedly, this is a very difficult challenge, not easily solved. With training, they will be able to react quickly and correctly and to face different disaster scenarios threatening them to know where their homes are to be located and how to make them safe against the area's hazards. UNESCO could help to strengthen the country's education regarding disaster reduction, so the UNESCO representatives in disaster-prone developing countries need to have knowledge and experience in earth sciences, management skills and personal motivation to promote education on DRM. In a developing country like Peru, there is an urgent need for such a UNESCO representative.

   However it is estimated that most of the developing countries do not have the critical mass of adequate level to implement such an immense task. In this regard, the IISEE, with a connection with the top professors and researchers of Japan, might facilitate this task by reducing the time so that such very valuable and important lessons and conclusions may reach the poor people of developing countries, so social inclusion is not only a semantic attempt, but it is really a task to be implemented.

12. The most important report on the Great East Japan Earthquake, prepared by the Japanese Government GFDRR and the World Bank (Rahangheri and Ishiwatari, 2014), consists of a set of 32 Knowledge Notes, grouped into six thematic clusters:
    1) Structural measures
    2) Non-structural measures
    3) Emergency response
    4) Reconstruction planning
    5) Hazard and risk information and decision making
    6) Economics of disaster risk, risk management and risk financing.

This report entitled “Learning from Megadisasters” is a very valuable document covering all phases of DRM, however the last thematic cluster is not so familiar to earth scientists, engineers and architects in Peru, and probably this is true in most developing countries. On the other hand, knowledge of economists on disaster risk reduction is scarce. So the author approached the Graduate Department on Economy of the University of Piura in Lima, and lectured on business continuity planning (BCP) and business continuity management (BCM). The lecture was as iterative as possible, to learn from each other. During the commemoration of the 140th anniversary of Japan Peru Diplomatic relations, both sides invited the author to offer a lecture on Business Continuity and Planning and the Economic Resilience in Peru. Its content was a proposal focused on the need for clusters to be included in a comprehensive DRM in Peru and other developing countries located in a disaster-prone region.

According to data existing in the USA, some 15 % of the total investment of a life cycle of an industrial project is dedicated to the conception and planning, including the investment on land purchase, construction and equipment procurement. The remaining 85 %, on average, is dedicated to operation and maintenance, In Peru and some other developing countries, maintenance is usually poor. If the industrial plant is affected by an intense natural phenomenon, and the damage is so important that the plant is put out of operation, the cost of structural repairs and reinforcement, and cost of replacing equipment, need to be charged to maintenance, including the production stoppage, and loss of clients, that may never be recovered. The production chain needs to be organized to include the close of the business, which is not usual; except in mining operations: when the mineral is exhausted, an important part of the total business planning needs to include the close of a mine to deal with the environmental liabilities.

According to Nomura Holdings, Inc., a Japanese financial holding included in the Nomura Group that provides investment and related services to individual and government customers on a global basis, with an emphasis on securities businesses, and also to the advice of Rahangheri and Ishiwatari (2014), the best way to implement Business Continuity Planning (BCP) and Business Continuity Management (BCM) is to investigate the lessons left by past disasters. In this sense it is interesting to mention an example that occurred during the 2011 Great East Japan Earthquake and Tsunami, with regard to the chain of production when one link failed and the whole production process collapsed. An important part of an automobile engine that was being manufactured in the Tohoku region had its production interrupted. This caused the reduction of the production of some 600,000 cars in Japan, the rest of Asia, Europe and the USA for about six months. This example shows that DRM needs to be treated holistically, to avoid the bankruptcy of industrial corporations in developing countries.

To absorb and apply the many lessons left by the megadisasters that have occurred in Asia and in Chile will take time, so developing countries need to make a great effort to apply the latest technology to protect their people and investments as soon as possible.

13. Education of the general public on basic knowledge of disaster risk reduction is essential in developing countries to save their lives, as they will face different scenarios, which they will have

to respond to quickly and adequately. The Kamaishi Miracle and how Chileans reacted during the 2010 tsunami are encouraging occurrences. In Chile, even though the alarm had been officially canceled due to a technical mistake, since the people felt a long and intense earthquake, most of them went ahead and evacuated the tsunami inundation zones to high lands.

With regard to education UNESCO might play a key role intensifying education on disaster risk reduction.

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REFERENCES

Adriano, B., Mas, E., Koshimura, S., Fujii, Y., Yauri, S., Jimenez, C., and Yanagisawa, H. (2013), Tsunami Inundation Mapping in Lima, for Two Tsunami Source Scenarios. Journal of Disaster Research. Vol. 8. N° 2 pp. 274-284 Mar. 2013.

Centro Virtual Cervantes Web Site, “Archivo General de Indias”, http://cvc.cervantes.es/obref/arnac/indias/, accessed December 8, 2014. (in Spanish)

Condori, J. (2013), Analysis and Design of Structures with Vertical Evacuation Resistant to Earthquake and Tsunamis, Master thesis in Civil Engineering theses. National University of Engineering. Lima-Peru.

CRYRZA (1972), Commission for Rehabilitation and Reconstruction of Zone Affected by the 1970 Earthquake, Government of Peru.

EERI (2012), Earthquake Spectra Special Earthquake Report_ June 2010 Learning from Earthquakes. The Mw 8.8 Chile Earthquake of February 27, 2010. Vol 28. Number S1, June 2012.

EERI (2013), Earthquake Spectra, 2011 Tohoku-Oki Earthquake and Tsunami, Special Issue, Vol. 29, No. S1.

GSI Web Site: http://www.gsi.go.jp/ENGLISH/index.html, accessed December 17, 2014.

Hammer, J. (2011), “The Great Japan Earthquake of 1923/ The powerful quake and ensuing tsunami that struck Yokohama and Tokyo traumatized a nation and unleashed historic consequences”, Smithsonian Magazine, http://www.smithsonianmag.com/history/the-great-japan-earthquake-of-1923-1764539/?no-ist, accessed December 17, 2014.

Hashimoto, M. (2013), Crustal Deformation Associated with the 2011 Tohoku-Oki Earthquake: An Overview, Earthquake Spectra, Vol.29, No. S1, p S81-S98.

IISEE (2014), Year Book –International Institute of Seismology and Earthquake Engineering-, Vol. 32.

IISEE Web Site: http://iisee.kenken.go.jp/, accessed December 17, 2014.

Imamura, F. (1996), "Review of Tsunami Simulation with a Finite Difference Method, Long-wave Runup Models". Scientific Public Publishing Co. Pte. Ltd. Singapore 1996.

Inter-American Development Bank (2013), Report to the Peruvian Ministry of Economy and Finance.

International Oceanographic Commission Web Site: “Indian Ocean Home”, http://www.ioc-tsunami.org/index.php?option=com_content&view=article&id=8&Itemid=58&lang=en , accessed December 15, 2014.

International Tsunami Survey Team: Araya S., J. Borrero, L. Dengler, B. Gomer, S. Koshimura, G. Laos, D. Olcese, E. Okal, M. Ortiz, M. Swensson, V. Titov and F. Vegas (2001), Impacts of the 2001 Peru Tsunami in Camaná, ITS 2001 Proceeedings, Session 2, Number 2-7, p409, http://nthmp-history.pmel.noaa.gov/its2001/Separate_Papers/2-07_Dengler.pdf, accessed December 15, 2014.

Jimenez, C., Moggiano, N., Mas, E., Adriano, B., Koshimura, S., Fujii, Y., and Yanagisawa, H. (2013), Seismic Source of 1746 Callao Earthquake from Tsunami Numerical Modeling, Journal of Disaster Research, Vol. 8, N° 2, pp. 266-273.

Kuroiwa, J. (2004), "Disaster Reduction. -Living in Harmony with Nature-", Editorial NSG SAC. Lima, Peru.

Kuroiwa, J. and Delgado, A. (2012), Resilient Cities, an Effective Way to Reduce Disasters, Proceedings. 15th World Conference on Earthquake Engineering 24 to 28 September 2012. Lisbon, Portugal.

Kuroiwa, J. (2010), Sabo Works for Debris Flow Disaster Reduction in the South American Andes. International Sabo Forum 2010. Toyama, Japan. October 7, 2010.

Kuroiwa, J. (2014), Peru Sustainable (Resilient) Cities Programme 1998-2012. Its Application 2014-2021. International Conference on Building Resilience. 2014. 8-10 September 2014, Salford Quays. United Kingdom, Proceedings of Economic and Finance. Elsevier.

Larsen, M. C., Wieczorek, G. F., Eaton, L. S., Morgan, B. A., Torres-Sierra, H. (2001), Natural Hazards on Alluvial Fans: the Venezuela debris-flow and flash-flood disaster: U.S. Geological Survey Fact Sheet, FS 103-01, 4 p., http://pubs.usgs.gov/fs/fs-0103-01/fs-0103-01.pdf, accessed December 13.

Munch Re (2004), "Annual Review: Natural Catastrophes in 2004", http://www.preventionweb.net/files/1528_30204321en.pdf , accessed in December 10, 2014.

NOAA Web Site: "2011/03/11 Tohoku Japan earthquake and tsunami", http://www.ngdc.noaa.gov/hazardimages/event/show/256, accessed December 17, 2014.

PTWC Web Site: Pacific Tsunami Warning Center, http://ptwc.weather.gov/, accessed December 15, 2014.

Rahangheri, F. and M. Ishiwatari (eds) (2014), "The Great East Japan Earthquake, Learning From Megadisasters", http://wbi.worldbank.org/wbi/megadisasters , accessed December 12, 2014.

Sawaji, O. (2012), "Education and Disaster Reduction", The Japan Journal, February 2012, p6-12 http://www.japanjournal.jp/home/wp-content/uploads/2012/02/1202e_06-10_CoverStory.pdf , accessed December 15, 2014.

Silgado E. (1974), Historia de los Sismos más notables ocurridos en el Perú" (1513-1974), Boletín N° 3, INGEMMET, Geological, Mining, and Metallurgical Institute. Lima, Peru (in Spanish).

Simons M., Minson S., Slaclen A., Ortega F., Jiang Owen S., Meng L., Ampuero J., Wei S., Cha R., Helmberger D., Kanamori R, Hetland E, Moore A, Webb F. (2011), The 2011 Magnitude 9.0 Tohoku-Oki Earthquake: Mosaicking the Megathrust from Seconds to Centuries. Science, Vol. 332, No. 6036, pp. 1421-1425.

UN-HABITAT, "The Sustainable Cities Programme in Peru", http://unhabitat.org/publications-listing/the-sustainable-cities-programme-in-peru/, accessed December 13, 2014.

United Nations (2010), Report to the Government of Chile of March 30, 2010.

University of Chile (2012), "Mw = 8.8 Chile Earthquake of February 27, 2010", Faculty of Physical Sciences and Mathematics, Department of Civil Engineering (in Spanish).

USC Tsunami Research Group Web Site: "1946 Aleutian Tsunami", http://www.usc.edu/dept/tsunamis/alaska/1946/webpages/, accessed December 15, 2014.

USGS Web Site-1: "Magnitude 9.1 - OFF THE WEST COAST OF NORTHERN SUMATRA", http://earthquake.usgs.gov/earthquakes/eqinthenews/2004/us2004slav/, accessed December 8, 2014.

USGS Web Site-2: "Magnitude 7.0 - HAITI REGION" http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010rja6/, accessed December 13, 2014.

USGS Web Site-3: "Earthquake with 1000 or More Death Since 1900", http://earthquake.usgs.gov/earthquakes/world/world_deaths.php, accessed December 13, 2014.

USGS Web Site-4: "Historic Earthquakes/ Peru /1974 October 03 14:21:29 UTC/ Magnitude 8.1", http://earthquake.usgs.gov/earthquakes/world/events/1974_10_03.php, accessed December 16, 2014.

USGS Web Site-5:"Historic Earthquakes/ Chile 1960 May 22 19:11:14 UTC/ Magnitude 9.5/ The Largest Earthquake in the World", http://earthquake.usgs.gov/earthquakes/world/events/1960_05_22.php, accessed December 13, 2014.

USGS Web Site-6, “Historic Earthquakes/ Peru 1970 May 31 20:23:27 UTC/ Magnitude 7.9”, http://earthquake.usgs.gov/earthquakes/world/events/1970_05_31.php, accessed December 13, 2014.

Wright, T. L. and T. C. Pierson, 1992, “Living with volcanoes”, USGS Circular: 1073, http://pubs.usgs.gov/circ/1992/1073/report.pdf, accessed December 14, 2014.

Yamazaki, F. and C. Zavala (2013), SATREPS Project on Enhancement of Earthquake and Tsunami Disaster Mitigation in Peru, Journal of Disaster Research, Vol.8, No.2, p224-234.