



RESILIENCE LESSONS LEARNED FROM SELECT RECENT EARTHQUAKES

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Abstract

Recent earthquakes have ravaged many communities in developed and developing regions alike. By tracking each significant event, we could learn many lessons that would help:

- (1) enhance the resilience of our community; and
- (2) assist other communities in developing regions to build up their capabilities to adopt appropriate measures compatible with local conditions to mitigate earthquake damage.

This paper covers earthquakes that occurred in recent decades that offered representative resilience lessons in various tectonic as well as socio-economic settings. It summarizes key features of select events including earthquake and damage data, physical and socio-economic conditions of affected areas. Community resilience involves both physical aspects such as housing and infrastructure as well as human aspects such as emergency response, care and gradual restoration of community health and normal function. Lessons gleaned from these events include:

- Issues related to active fault;
- Management of traditional and compound secondary hazards;
- Vulnerable buildings;
- Lifeline facilities;
- Earthquake Preparedness and Response; and
- Institutional support.

As recent experiences show, the interaction of an earthquake with our ever increasingly concentrated socio-economic development, could result in heavy casualties, serious damage to our livelihood, economy, and environment. We have no other choices but to learn from our collective experiences, and to implement those lessons appropriate to our situation to mitigate the impact of future earthquakes.

Keywords: Multi-Hazards, Early Warning, Emergency Response, Seismic Resistance, Restoration



1. Introduction

Resilience to earthquake requires continual and sustained efforts throughout the entire process of preparation for a seismic event through emergency response, temporary care and maintenance all the way to long-term restoration. This paper discusses some of the resilience-lessons gleaned from earthquakes that occurred in recent decades. A summary of relevant facts for some of these selected events is summarized in Table 1. A similar table for the rest of the events was given in [1], and is not repeated here to save space. However, those events are listed below:

- Dec. 26, 2003 Bam EQ, Southern Iran (Asia Continent);
- Dec. 26, 2004 Sumatra EQ Indonesia (Indian Ocean);
- May 12, 2008 Wenchuan EQ China (Asia Continent);
- Jan. 12, 2010 Haiti EQ (Caribbean Sea);
- Feb. 27, 2010 Maule (36 km east of Khudi offshore Bio-Bio) EQ Chile (South Pacific Ocean);
- Sep. 4, 2010 Darfield (Canterbury) EQ New Zealand (South Pacific Ocean);
- Feb. 22, 2011 Christchurch EQ New Zealand (South Pacific Ocean); and
- Apr. 25, 2015 Gorkha (36 km east of Khudi) EQ, Nepal (Asia Continent).

Each earthquake presented in Table 1 is briefly discussed in the following section. The remaining paper covers general discussion about the resilience-related issues involving all selected earthquakes, when relevant.

2. Earthquake Events

2.1 1999 Kocaeli (Izmit) and Düzce Earthquakes in Turkey

On August 17, 1999 a magnitude Mw 7.4 earthquake occurred in the Kocaeli and Sakarya provinces of Turkey, a densely populated industrial heartland of northwestern Turkey. Three months later, on November 12, at the eastern end of the August fault break the adjacent segment of the North Anatolian Fault system ruptured, producing the Mw 7.1 Düzce earthquake [2]. This pair of earthquakes resulted in heavy casualties and economic damages in the extended swath of affected area (see Table 1). To better understand the national fault activities, Turkey government engaged a multi-disciplinary and multi-lateral research project to monitor these faults from 2005 to 2010 (see Fig. 1, [3]). Ongoing monitoring beyond 2010 is expected to continue in similar programs based on available resources and perceived research objectives. Figure 2 shows Bolu viaduct damaged during both the Kocaeli and Düzce earthquakes. The lower left inset shows the local fault crossing the viaduct pier foundation plan, while the upper right inset indicates displaced super-structure [4].

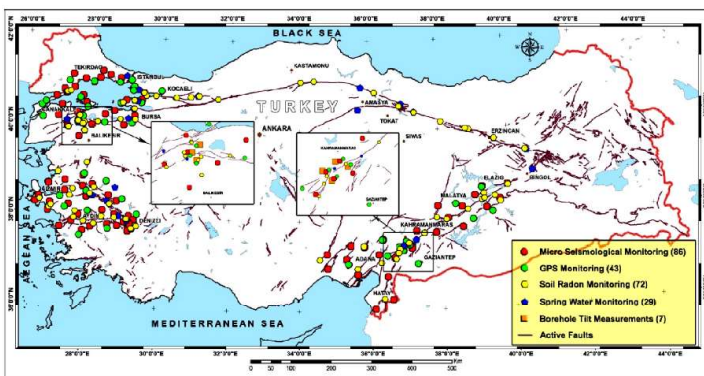


Fig. 1 - Turkey seismic monitoring stations in the TÜRDEP project (from Inan S et al. 2010, [3])

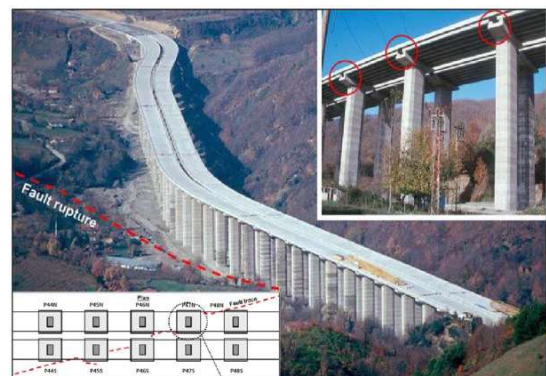


Fig. 2 - Bolu Viaduct during 1999 Düzce EQ (from Yang and Mavroedidis 2018,[4])



2.2 2009 L'Aquila Earthquake in Italy

Figure 3 shows the historic seismicity of L'Aquila area [5]. The most significant earthquakes in the area are: those of 1315 ($M_w > 6.7$); 1349 ($M_w > 6.5$); 1461 ($M_w > 6.5$); 1703 ($M_w > 6.7$); and 1915 ($M_w > 7.0$). Thus, the 2009 series of seismic events: M_w 6.3 April 6; M_w 5.6 April 7; and M_w 5.4 April 9 fit the historic seismicity pattern quite well. However, the nearest significant event prior to 2009 occurred 94 years ago. The current generation of the residents had little collective experience of severe earthquakes.

Since October 2008, earthquake tremors had unnerved the local population. The “prediction” of a pending large earthquake issued by Mr. Gioacchino Giuliani, an amateur seismologist and technician at Italy's National Institute of Nuclear Physics, seemed to have further stirred up the public anxiety. On March 31, 2009, the National Commission for Prediction and Prevention of Major Risks convened in L'Aquila to assess the earthquake swarms, and held a press conference. According to the minutes, Mr. Enzo Boschi, President of the National Institute of Geophysics and Volcanology indicated that “it is unlikely that an earthquake like the one in 1703 could occur in the short term, but the possibility cannot be totally excluded.” During the press conference, Mr. Bernardo De Bernardinis, then deputy chief of Italy's Civil Protection Department, might have been influenced by the desire to dispel the public alarm caused by Mr. Giuliani's “prediction” of a large earthquake and conveyed a reassuring opinion [6].

Unfortunately on April 6, 2009, a magnitude 6.3 earthquake hit L'Aquila and its vicinity followed by two large aftershocks in next 3 days, killing more than 300 people and injuring more than 1,500. The quake destroyed about 20,000 buildings and displaced 65,000 people. Figure 4 shows the damage scene at Castelnuovo, a hilltop town [5]. A contribution of 470 million Euros and other post-earthquake initiatives were made by the EU to assist local communities.

In 2010, an indictment was made against Mr. Bernardo De Bernardinis and six other earthquake scientists, charging them with manslaughter and negligence for failing to warn the public of the impending risk. The seven defendants were convicted of manslaughter in 2012 and each received a six-year jail sentence. The court case went through two levels of appeals and reached the Italy Supreme Court. In November 2015, the Supreme Court acquitted the six scientists, but kept a reduced two-year sentence on “suspension” for Mr. De Bernardinis. This landmark court case illustrates how complex the interplay of the respective roles among stakeholders could become, when facing a potential impending significant seismic event with increasing seismic activities lurking in the background.

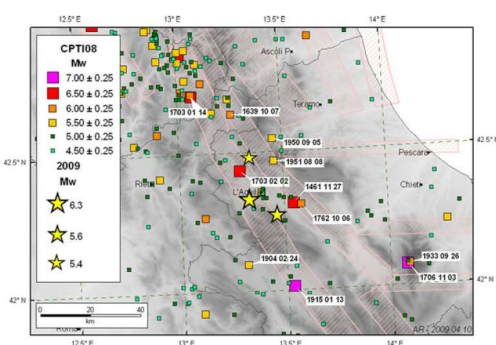


Fig. 3 - Historic seismicity in the vicinity of L'Aquila (from GEER 2009, [5])



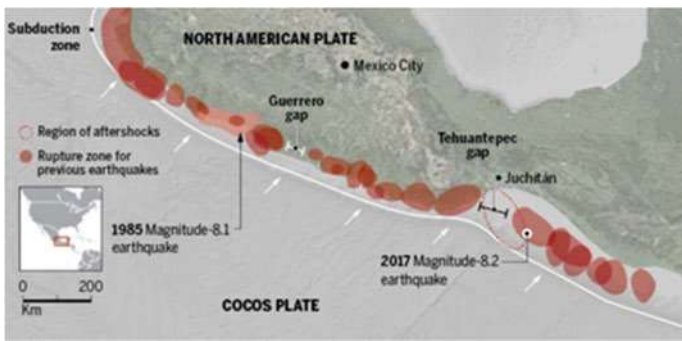
Fig. 4 - All structures in Castelnuovo on a hilltop were totally or partially collapsed (from GEER 2009,[5])

2.3 2017 Puebla-Morelos Earthquake in Mexico

As history would have it, the 2017 M_w 7.1 Puebla-Morelos intraplate event occurred on September 19, 2017, coincidental to the 32nd anniversary of the 1985 M_w 8.0 Michoacan interplate event (see Fig. 5a,[7]). The 2017 earthquake occurred as a result of normal faulting at a depth of approximately 50 km. While the problem of ongoing ground subsidence due to extraction of groundwater in the Mexico City is widely recognized for decades, the somewhat related problem of ongoing ground cracking and its intensification during seismic



events has only recently been systematically studied since 2005[8]. Mexico City, with its frequent seismic events and unique sensitive lacustrine-deposits subsoil, the ongoing structural deterioration of its building stock by repeated earthquake assaults is both a concern and a tough issue to address. This is further discussed in Section 3.3. Figure 5b shows a commercial reinforced concrete building retrofitted with steel cross bracings after the 1985 earthquake. The retrofitted building performed well in the 2017 event. The long-term goal of the city is to improve the seismic resistance of existing building stocks by retrofitting and/or replacement [8].



(a) Cocos Plate Subduction zone

(b) Steel bracing of reinforced concrete commercial building

Credits: (Graphic) G. Grullón, and V. Kostoglodov

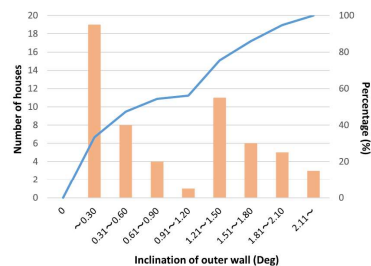
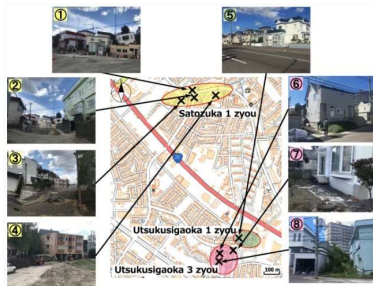
Fig. 5 Puebla-Morelos Mexico Earthquake (from CAEE 2019, [8])

2.4 2018 Ibuji-tobu (Tomakomai) Earthquake in Hokkaido, Japan

The Mw 6.6 earthquake occurred at 3:08 am local time, on September 6, 2018 in Ibuji-tobu (Tomakomai), Hokkaido, Japan. It involved the rupture of a blind reverse thrust fault, 14 km long and 15.9 km wide at a depth of 35 km. The depth to the top of the fault rupture was 16.2 km, and the slip was about 1.3 m. The peak ground acceleration was up to 0.3g to 0.6 g in epicentral areas. The main shock was preceded by a typhoon that saturated the ground, resulting numerous landslides and localized liquefaction during the earthquake.

The seismic event caused 42 fatalities (including 36 due to triggered landslides). There were 731 injured people, including 31 of severely injured. Completely destroyed houses were 462; partially destroyed houses were 1,570 with 12,600 slightly damaged houses. Power outage for 2.95 million households lasted from Sep. 6 to Oct. 4. Water supply was disrupted in Sapporo and other cities. At Atsuma, near epicentral area, the loss of water supply lasted for ~1 month (TCLEE 2019,[9]).

Serikawa et al.2019 [10] carried out an investigation to study the tilting of houses affected by liquefaction at Satozuka and Utsukushigaoka towns in Sapporo city. Figure 6a presents photos of houses affected by liquefaction in the two towns. Figure 6b shows the distribution of degree of tilting of the outer wall of these houses. The study indicates when the degree of tilting exceeded 0.6 degree, residents tended to move out from the house rather than continued to tolerate the deformed house condition.



(a) Liquefaction induced house damages

(b) Histograms of house inclinations

Fig. 6 - Liquefaction affected areas in Kiyota Cho, Sapporo Hokkaido (from Serikawa et al. (2019)[10])



Table 1 – Relevant Earthquake and Damage Data for Select Earthquakes

Earthquake Location/ (Local Time)	Earthquake Features	Casualties / Damages	Conditions After Earthquake		General References
			Physical	Socio-economic	
Kocaeli (Izmit) Turkey (Euro-Asia Continent) Crustal EQ Aug. 17, 1999 (3:01 am)	Mw 7.4 depth 17 km North Anatolian Fault Right-lateral strike-slip bilateral rupture 120 km Offset ~ 2.5 m to 4.5 m PGA up to 0.3 g to 0.4 g Strong shaking ~ 37 secs Intensity MMI (VI to IX) Water waves up to 2.5 m in Gulf of Izmit due to land subsidence and bank slumps, Site amplification of shaking in Avcılar	Fatalities >17,118, injured ~50,000 General damage ~\$8 billions, lifeline damage ~\$1 billion Fire damage at Tüpras oil refinery Significant damage to telecommunication, highway, railway, port, jetty, water, sewer and power transmission systems, Collapse of Arifiye over-pass due to fault offset	120-km zone of the North Anatolian Fault ruptured between Karamürsel and Golyaka Non-ductile reinforced concrete frame buildings with masonry infilled walls bulk building stock suffered substantial damages and collapses	~A half million people became homeless, and substantial loss of sustaining businesses and job opportunities Schools and private hospitals suffered substantial damages except public hospitals performed relatively well due to better design	USGS (1999)Erdik (2001)
Düzce Turkey (Asia Continent) Crustal EQ Nov. 12, 1999	Mw 7.1 depth 10 km Düzce Fault Right-lateral strike slip rupture 40 km Offset: horiz. 2.7 m to 4 m vert. 10 cm to 150 cm PGA up to 0.5 g to 0.8 g Intensity MMI (VI to IX)	Fatalities >894, injured 4,948 most in the Bolu-Düzce area, Landslides in the Bolu Pass, Bolu vehiduct bearings failure and girder movements, A sinkhole formed over the collapsed Bolu tunnel	Fault ruptures and landslides Damage concentrated in Düzce and Kaynasli West-bound lane of E-5 highway failed at Bakacak due to landslide	Collapsed and damaged buildings displaced people	USGS (1999) Erdik (2001) Yang and Mavroicidis (2018)
L'Aquila Central Italy Crustal EQ Apr. 6, 2009 (03:32)	M 6.3, depth 8.8 km Rupture of a normal fault L'Aquila located on hanging wall Max PGA ~0.1 to 0.4 g EMS 98 Intensity VI to IX Main shock preceded by a long period of tremors from October 2008	Fatalities >295, injured 1,000 Extensive damage in the old city of L'Aquila and surrounding areas Unreinforced masonry and reinforced concrete buildings suffered significant damages	Collapse of a 3-span bridge and some damages to other bridges, Two sinkholes formed in roads, and pipelines breaks due to fault displacements	55,000 homeless Due to 10,000 to 15,000 buildings heavily damaged or collapsed	USGS (2009)GEER (2009) EEFIT (2009) Pielke (2011)
Puebla-Morelos, Mexico Intraplate EQ Sep 19 2017 (13:14:38)	Mw 7.1, Depth 48 km Normal fault Intensity up to VI - VII in Mexico City due to site amplification of ground shaking in lake zones	Fatality >220 in Mexico City, 142 in other cities, injured ~6,000 Cost of damage estimated at ~\$2 billion, > 44 buildings collapsed, many others damaged in Mexico City, Significant damages in electric grid, water and sewer lines particularly in Colonia Del Mar, some collapsed and damaged bridges and Metro Line 12 elevated viaduct	Ground cracking caused significant damages in buildings, roads, water/sewer lines in Colonia Del Mar and Cienega San Gregorio of Mexico City	Displacement of residents in areas with destroyed or heavily damaged buildings	USGS (2017) GEER (2018) Post (2017) Alberto et al. (2018) CAEE (2019) Lo (2022)
Iburi-tobu (Tomakomai) Hokkaido, Japan Crustal EQ Sep. 6, 2018 (3:07)	Mw 6.6 depth 35 km Reverse thrust blind faulting, rupture plane 14 km long and 15.9 km wide, Depth to top of rupture 16.2 km PGA up to 0.3 g to 0.6g in epicentral areas Main shock preceded by a typhoon that saturated the ground, causing numerous landslides and localized liquefaction	Fatalities 42 (including 36 due to landslides) Injured 731 (including 31 of severely injured) Completely destroyed houses 462, partially destroyed houses 1,570 and slightly damaged houses 12,600 Numerous landslides and localized liquefaction areas, Power outage for 2.95 million households from Sep. 6 to Oct. 4, Water supply disruptions for Sapporo and other cities (at Atsuma near epicentre disruption lasted~1 month)	Liquefaction occurred in Satozuka and Utsukushigaoka, Kiyota Cho of Sapporo city	Liquefaction damage in Satozuka and Utsukushigaoka caused severe tilting of houses that some of these became no longer inhabitable	USGS (2018) TCLEE (2019)
Palu Indonesia (West Pacific Ocean) Crustal EQ Sept. 28, 2018 (18:02:45)	M _w 7.5 Depth 20 km Agriculture practice of wet rice fields caused wide spread liquefaction, EQ induced Tsunami run-up amplified locally by submarine landslides	Fatality>2,077, and Missing 1,075 Injured 4388, Displaced 206,524 68,451 houses damaged or destroyed Damage estimated at \$911 million Bridges and roads damaged, power and telecommunication outages occurred in Sulawesi Tengah	Co-seismic land subsidence Inundation by tsunami run-up Liquefaction caused damage of houses and rice fields	Significant impact on socio-economic development of the affected areas	USGS (2018) Socquet et al. (2019) Carvajal et al. (2019) Bradley et al. (2019)

Notes: USGS - U.S. Geological Survey; GEER- Geotechnical Extreme Events Reconnaissance; EEFIT- Earthquake Engineering Field Investigation Team



2.5 2018 Palu Earthquake in Indonesia

The September 28, 2018, Mw 7.5 earthquake near Sulawesi, Indonesia occurred as a result of strike-slip faulting at 20 km depth within the interior of the Molucca Sea microplate, part of the broader Sunda tectonic plate. The earthquake caused at least 2,077 fatalities, 4,438 injured, and 1,075 missing. Houses damaged or destroyed were 68,451 and displaced 206,524 people. Bridges and roads were damaged. Power and telecommunication outages occurred in Sulawesi Tengah due to the combined effects of the earthquake, tsunami, liquefaction and landslides. The towns of Balaroa and Petobo were submerged due to liquefaction. A tsunami with an estimated wave height of 7 m was observed at Palu. Damage estimated at \$ 911 million US dollars [11]. A post-event survey found that a number of cellular technology devices such as two-way radio system and satellite phone were reliable devices to use during the emergency response coordination. In addition, the mobile Base Transceiver Station (BTS) technology could be used to cover the needs of communication for people living in disaster-prone areas [12].

Carvajal et al. (2019,[13]) indicated that the Palu earthquake produced tsunami waves larger than usual strike-slip fault rupture events. This is likely related to the long and narrow Palu Bay's bathymetric features and additional non-tectonic local submarine landslides. Figure 7 shows comparisons of observed and modelled tsunami waves [14] along the Palu Bay.

Bradley et al. (2019, [15]) described another liquefaction hazard related to wet rice irrigation practice at Palu. Figure 8 illustrates this problem schematically (Keane 2019,[16]). The upper figure shows an up-slope irrigation canal and rice paddies and fields down slope. The aqueduct-supported cultivation, primarily of wet rice, raised the water table to near ground surface, saturating sandy alluvial soils. The lower figure depicts the aftermath of the earthquake-triggered liquefaction of the saturated ground at a gentle slope of $\sim 1^\circ$. Long-runout landslides and debris flows then swept through villages occupying the gentler slopes below.

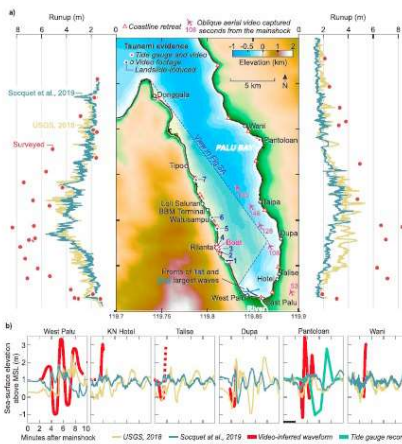


Fig 7 - Observed and modelled tidal waves along Palu Bay (from Carvajal et al. 2019 [13])

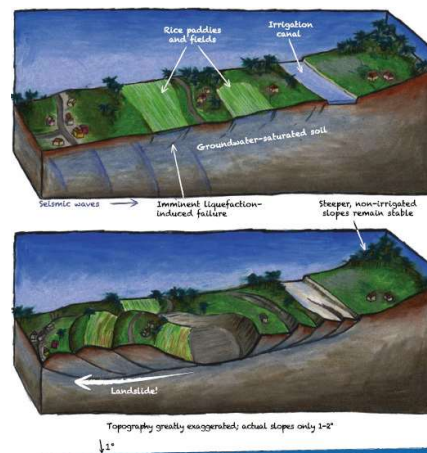


Fig. 8 - Landslides by liquefaction (from Keane 2019 [16])

3. Resilience Related Issues

This section discusses following six resilience-related issues with reference to select earthquakes covered in the introduction section when appropriate:

- Active Fault;
- Earthquake Secondary Hazards;
- Vulnerable Buildings;
- Lifeline Facilities;
- Earthquake Preparedness and Response; and
- Institutional Support.



3.1 Active Fault

Active fault poses special problems for structures built over and near it. In addition to strong shaking at these locations, permanent dislocation of the ground across the fault would cause further structural damages. Thus, local jurisdictions often prohibit building over active faults like the California State in the U.S. Other precautions are relatively higher vertical acceleration in areas within 20 km of a fault zone than at locations further away.

Ulusay et al. (2018,[17]) discussed the behaviour of structures built on active fault zones using examples of the 1999 Kocaeli (Izmit) and Düzce earthquakes. Yang and Mavroeidis (2018,[4]) provided a review of bridges crossing fault rupture zones including those involved in the 1999 Kocaeli (Izmit) and Düzce earthquakes in Turkey and the 2008 Wenchuan earthquake in China.

3.2 Traditional and Compounded Earthquake Secondary Hazards

Traditional secondary earthquake impacts include tsunami, fire, landslide, debris flow and liquefaction, etc. Earthquake induced failure of modern industrial facilities could be considered as compounded failure. The meltdown of 3 nuclear reactors at the Fukushima Dai-ichi power plant in Japan caused by the 2011 Tohoku earthquake-tsunami and the fire damaged Tüpras oil refinery in Turkey in the 1999 Kocaeli (Izmit) earthquake are two of the more noted examples. Other examples of compounded hazards include destruction of chemical plant, fuel and hazardous-waste storage facility and breach of major reservoir and tailings impoundment.

Economist (2021,[18]) pointed out following key impacts of the 2011 nuclear meltdown, 10 years after the incident:

- There are 36,811 people who cannot return to their home in the “difficult to return” zones within ~30 km of the plant in the northwest direction due to radioactive contamination.
- The accumulation of more than 1 million tonnes of contaminated radioactive water, containing mainly tritium isotope and other dangerous content.
- Safe decommissioning of the plant, including the removal of 900 tonnes of melted fuel, is estimated to require ~30 to 40 years.
- Contribution of nuclear power generation in future energy supply in Japan and other countries such as Germany seems to lose public support.

3.3 Vulnerable Buildings

In the 1985 earthquake, buildings in Mexico City with following characteristics suffered significant damage or collapse: steel structure with beam to column connections unable to resist forces associated with plastic hinges formed in the beams; reinforced concrete frame structure with masonry infills or with flat plate (either waffle slab or slab with hollow masonry filler blocks); non-ductile structure; masonry structure; or structure with inadequate detailing required for ductility provision (EFFIT 1986,[19] and NTIS 1987,[20]). Buildings of similar characteristics shared the same fate in the 2017 seismic event. Building damages included: total or partial collapse, mid-height floor collapse, soft story, diagonal shear, torsional shear due to eccentricity, pounding with adjacent buildings (Post 2017,[21] and Alberto et al. 2018,[22]). Slender buildings with high slenderness ratio tended to fail by overturning involving foundation bearing pressure failure or pull-out of piles. Differential settlement or tilting of buildings also occurred in both earthquakes. In 1985, some buildings seemed likely to have sunk due to foundation bearing pressure failure.

The building retrofit techniques observed in 2017 include: column strengthening and frame bracing. Successful seismic retrofits can be achieved when designed by competent structural engineers and constructed by experienced contractors. On the other hand, some buildings altered by owners without engaging competent engineers and contractors performed poorly in the earthquake.



3.4 Lifeline Facilities

In the 1985 earthquake, damage and collapse of SCT communications building caused disruption of long-distance telecommunication over three weeks. Several medical facilities and school buildings were also damaged and collapsed. In the 2017 earthquake, water and sewer lines were damaged, especially in the Colonia Del Mar area, where shallow faulting and ground surface cracking occurred (Eidinger and Maison 2018,[23]). Many of these damages occurred earlier in the 1985 quake (GEER 2018,[24]). Two segments of the elevated viaduct of Metro Line 12, about 1.2 km apart, suffered structural damage in 2017: one involved a column failure near its base with spalled concrete and exposed re-bars, and the other involved failure of concrete restraint at the shear keys of steel girders. Rocking motion of column pier appeared to be the cause at both locations. The repairs were ongoing during our October visit (CAEE 2019,[8]). Two parallel 5-span overpass bridges experienced rocking motion of wall piers with some damage at an abutment and minor tilt of some wall piers. Also, a span of a pedestrian overpass bridge appeared to have displaced off its central pier.

3.5 Earthquake Preparedness and Response

This section discusses external expert supports to El Salvador in dealing with its natural hazards associated with earthquakes, floods and landslides, earthquake early warning system in general and tsunami early warning system for countries around the Indian Ocean. The International Strategy for Disaster Reduction (ISDR (2006,[26]) issued a concise checklist for developing people-centred early warning systems. It has four main components: (1) risk knowledge – systematically collect data and undertake risk assessments; (2) monitoring and warning service – developing monitoring and warning services; (3) dissemination and communication – communicate risk information and early warnings; and (4) response capability – build national and community response capabilities.

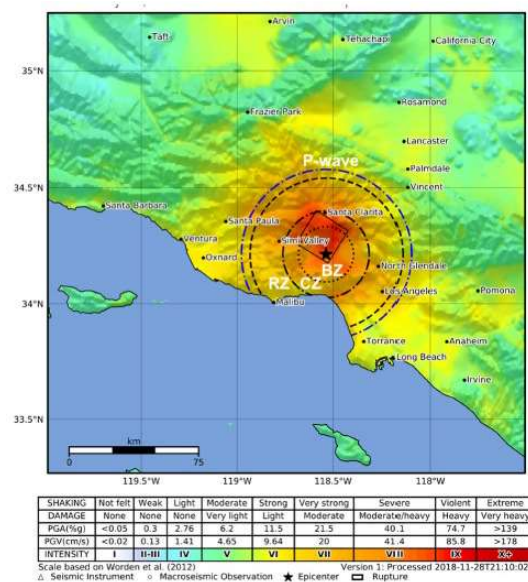
- Adaptation to Earthquake and Landslide Hazard in El Salvador – Jibson and Crone of USGS (2001, [27]) conducted a field review for the Salvadoran government from Jan. 31 to Feb. 9 regarding landslide hazards related to the January 13, 2001 M-7.6 El Salvador earthquake, and provided expert assessments and recommendations. Anderson et al. (2012,[28]) described the use of space-based data support services regarding the 2009 floods and landslides hazards in El Salvador. They indicated that this support should span different phases of the disaster management and public policy cycles. These external expert supports are dearly needed in the densely populated country with serious natural hazards.
- Earthquake early warning system has been developed and used in many parts of the world. Wald, in his overview (2019 [29]), stressed the importance of two points: (1) effective warning time is relatively short, and depends on the focal mechanism of an earthquake. For an inter-plate earthquake the warning time could be a few tens of seconds. This critical time reduces to a few seconds to ~20 seconds for an intra-plate earthquake, and further shrinks to a single-digit seconds for a crustal earthquake. (2) It is challenging for a person to take effective mitigating actions in such a short period of time to reduce fatality or injury let alone property loss. Figure 9 shows estimated warning time available for 1994 M6.7 Northridge, Calif. Earthquake. In the estimate, 2 seconds were allowed for communication latency, and 5 seconds were assumed for response time.
- The German-Indonesian Tsunami Early Warning System, GITEWS [30], was developed to address a major problem revealed in the Dec. 26, 2004 Sumatra EQ in Indonesia. About a quarter million people perished around the Indian Ocean due to the fact that there was no early warning system in existence then. Under the auspices of the Inter-governmental Oceanographic Commission of UNESCO, an international system had been set up in two phases:
 - GITEWS phase (2005 to 2011) - The system consisted of 25 seismographic stations and six Deep-ocean Assessment and Reporting of Tsunamis (DART) sensors, relaying information to 26 national tsunami information centers. It became active in late June 2006, following the leadership of UNESCO.
 - PROTECTS phase (2011 to present) - Since March 29, 2011 the system operator has been the Meteorological, Climatological and Geophysical Services (BMKG) in Jakarta.



Performance of this system in recent years were problematic Telegraphic (2018,[31]). An UNDRR (2019,[32]) study on the performance of the system in the 2018 Palu earthquake indicated the following:

1. The system did not function properly. The tsunami arrival time in Palu and Donggala was too short for the current system to detect and issue early warning.
2. The current system needs further improvements to provide a people-centred warning system that would enhance the protection of people at the community level.

To further the advancement of disaster and development paradigm, Collins (2018,[33]) proposed sustained investment in: early buildup of well-being before a disaster, better living with uncertainty, and overcoming the barrier to desired disaster and development outcomes. His proposal was based on his local action research carried out with marginalized and highly at-risk groups of people in Southern Africa and South Asia.



Note: BZ Blind Zone (No Alert Zone); CZ Communication Zone (2 second allowance for communication latency); RZ Response Zone (5 second allowance for response time)

Fig. 9 - Warning time available shown on a Shake Map for 1994 M6.7 Northridge, Calif. Earthquake (from Wald 2019 [29])

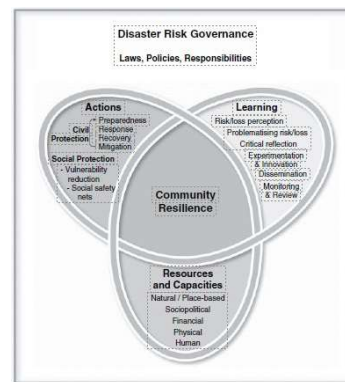
3.6 Institutional Support

Karanci et al. (2015[34]) provided a review of individual and community resilience to earthquakes using a case study of two Turkish regions: Van (October 23, 2011 Mw~7.1 earthquake, see Fig. 10a) and Adapazarı/Sakarya (August 17, 1999 Mw~7.4 earthquake). Before 1999, the focus of disaster management in Turkey was mainly on the response and recovery. However, after the two catastrophic 1999 earthquakes mitigation of risk became a particular focus of governmental policies. With the technical and financial support of the World Bank, the Turkish Catastrophe Insurance Pool (TCIP) was introduced in 2010. Moreover, the Disaster and Emergency Management Presidency (AFAD) was established in 2009 as a central coordinating agency for all institutions to deal with disasters. The 2015 review suggested that with the central coordination of AFAD, the government's response and handling of Van earthquake was more organized and efficient than in 1999. The TCIP catastrophe insurance pool also shared some of government financial burden for post-disaster reconstruction.

Carter (2015,[35]) also discussed resilience lessons related to the 2004 Sumatra tsunami and 2010 Haiti earthquake. In both events, the local socio-economic conditions played a significant role in the development



and outcome of community rebuilding process. In Aceh and Nias, the Indonesia government set up the Rehabilitation and Reconstruction of Aceh agency to deal with the reconstruction task at Aceh and Nias for a duration of 4 years. A multi-donor fund was established to facilitate the management of all relief-funds. The agency also needed to handle the Aceh secessionist' sentiment among all other regular activities. In Haiti, the Interim Haiti Recovery Commission, co-chaired by Haiti Prime Minister Bellerive and UN Special Envoy Clinton, was set up to operate for 18 months. However, the operation was carried out with weak coordination. Thus, recovery activities tended to be carried out by various parties without a common focus and agenda. The weak national institutions as well as its poor financial situation remain to be Haitian main weakness in its normal as well as emergency operations.



(a) Emergency Response for 2011 Van earthquakes (b) Community Resilience - Resources, Learning and Actions

Fig. 10 - A Case Study from Turkey (from Kranci et al. 2019 [34])

4. Summary

The occurrence of earthquake follows some unknown function in time. It proceeds in a cycle of energy release in a given seismic event followed by a gradual build up of potential energy to a critical phase of triggering the next event. Although the exact nature of this time function remains unknown to us at present, we have learned collectively by experience how to survive such a traumatic event as well as how to better prepare for the next event. Thus, our effort to develop resilience to earthquake hazard should span all the phases of an earthquake cycle from pre-disaster awareness to real-time monitoring, through emergency response to post-disaster impact assessment, all the way to recovery effort and identifying lessons learned for improving our performance in the next cycle. This paper gleans resilience-related lessons from recent earthquakes around the world with the objective to highlight some of the recurrent as well as new issues.

5. Acknowledgements

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