Structural Engineering

A survey of earthquake-induced damage to telecommunications towers (1999-2011)

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Department of Civil Engineering and Applied Mechanics

McGill University
Montreal

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Preface

The author and her supervisor, Prof. Ghyslaine McClure, recently worked on a research aimed at validating computational seismic response predictions of a guyed telecommunication mast with ambient vibration measurements. This report summarizes telecommunication towers damages due to recent earthquakes (from 1999 to 2011) as reported in damage reconnaissance accounts openly accessible.

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1. Introduction

Telecommunication structures are essential components of communication and post-disaster networks that must remain operational especially after design-level earthquakes. Also preservation of these structures, as critical links of personal communication, has high priority in the seismic-prone regions of the word. These structures are generally designed for supporting elevated antennas for radio and television broadcasting, mobile phone base stations, telecommunication, two-way radio, and single channel customer connections such as microwave links that support air services, electricity organizations, railways.

Despite the importance of these towers, there are few available reports that document tower damage in connection with earthquakes compared to that related to wind and ice. In Canada, no seismic damage has ever been reported on telecommunication towers. A similar 1999 survey by Schiff documents reports of only 16 instances of tower damage related to seven important earthquakes since 1949, none of which having been a direct threat to life safety.

Table 1 summarizes available information on telecommunication equipment damages in recent earthquakes, from 1999 till 2011.

A summary of some of these damages is presented in chronological order of occurrence in the next section.

Table 1. Summary of telecom equipment damage in recent earthquakes (since 1999)

Magnitude	Peak horizontal ground acceleration (on Site Class C)	Date, Location	General	Specific structural failures	Rooftop structures	Functional failures
9.1 to 9.3 Mw; 9.3R	**Not recorded (Ocean Indian source)**	**26 Dec 2004, Sumatra Tsunami**	**Extensive damage caused by tsunami.**	**70-m steel SST in Hambantota struck by floating object.**		**100M US$ of damage to Sri Lanka Telephone**
9.0 Mw	**0.35 g**	**11 March 2011, Sendai, Japan Tsunami**	**Early to tell. Unknown number of structures destroyed by tsunami.**			**Disruption due to power outages; some structures destroyed by tsunamis. Shaking in Tokyo.**
8.8 Mw	**0.65 g**	**27 February 2010 Chile**		**One monopole toppled due to poor soil; another mounted on a collapsed concrete tank.**	**Several cell sites collapsed with buildings. Roof top antenna mount failure (photo)**	**Most cell sites ran out of power. 50% of cell sites had damages to batteries (racks unanchored). Fallen antennas from towers still standing.**
8.0 Mw	**0.56 g**	**15 Aug 2007, Pisco, Peru**				
7.8 Mw	**0.98 g**	**12 May 2008, Sichuan, China**	**More than 2800 cell towers collapsed. 16500 wireless stations damaged. (one photo of damaged cell site at Hongkou)**			**Extensive damage of building enclosures of switching stations, power supply failures. Damage or misalignment of microwave antennas.**

Table is continued in the next page.

Magnitude	Peak horizontal ground acceleration (on Site Class C)	Date, Location	General	Specific structural failures	Rooftop structures	Functional failures
7.7 to 7.9 Mw	**1.13 g**	**13 January 2001 El Salvador**				
7.6 Mw; 7.9 R	**0.38 g (estimated)**	**26 January 2001, Bhuj, Gujarat**	**Towers standing.**	**Tower standing east of Kunbar River (photo)**		**Serious disruptions linked to emergency power supply.**
7.6 Mw	**0.7 g (estimated)**	**8 October 2005, Kashmir, Pakistan**	**TV tower collapsed. Several structures affected.**		**Several building collapses.**	**Extensive. Service restored quickly with deployment of emergency structures.**
7.6 M	**1.0 g** **Also 0.73 g vert.**	**21 September 1999, Chi-Chi, Taiwan**	**No report of ground telecom structure failures.**		**Several building collapses. Many rooftop installations on collapsed buildings.**	**Widespread disruption of cellular phone services due to damages (structural and non-structural) to central offices, poor performance of power back up system (batteries discharged), antenna damage, etc.**
7.4 Mw	**0.41 g**	**17 August 1999, Izmit, Turkey**	**No specific telecom tower failure reported.**			**Widespread disruption of wireless services.**
	Aftershock of Sumatra 26 dec 2004	**13 Jan 2005 South East Asia**		**SST failure due to impact of object in tsunami. (India)**		

Table is continued in the next page.

Magnitude	Peak horizontal ground acceleration (on Site Class C)	Date, Location	General	Specific structural failures	Rooftop structures	Functional failures
7.0 Mw;7.3 R	(above 0.4 g – info missing)	2 Sep 2009 West Java				
7.6 Mw	0.4-0.6 g (estimated)	30 Sep 2009 Padang, Sumatra	No structural failure reported.			Cellular phone disruptions for 10 days. Power supply issues. Service restored with transportable masts.
7.2	0.58 g	4 April 2010 El Mayor – Cucapah, Mexico				
7.2 Mw	0.32 g measured 0.35-0.40 g estimated	16 October 1999 Mojave Desert Hector Mine	Inhabited region. No damage.			
7.0 Mw	0.5 g	12 Jan 2010 Léogâne, Haïti	Devastation	One tall SST still standing in Port-au-Prince (photo).		Service restored quickly with deployment of emergency structures.
7.1 Mw	1.26 g	4 Sept. 2010 Canterbury, NZ				Power, batteries
7.1 R		28 May 2009, Honduras				Disruptions but no physical damage
6.8 Mw	0.25 g	28 Feb 2001 Nisqually, WA	No damage to TC structures reported. Damage to control tower at airport.			
Table is continued in the next page.						

Magnitude	Peak horizontal ground acceleration (on Site Class C)	Date, Location	General	Specific structural failures	Rooftop structures	Functional failures
6.6 Mw	**0.8 g (1.0 vertical)**	**26 Dec 2003, BAM, Iran**	**Minor damage to several structures.**		**Several RTS damaged**	**Non structural damage.**
6.3 Mw	**1.88 g (2.2 g at epicenter)**	**22 Feb 2011, Christchurch, NZ**	**Cell towers seriously damaged.**	**Bent monopole structure in downtown CHCH (photo)**		**Several disruptions.**
6.3 Mw	**0.3 g – 0.65 g**	**6 April 2009, L'Aquila, Italy**				

2. A review of communication tower failures in past earthquakes

2.1. 2001 Gujarat earthquake (India)

Earthquake at a glance*:*

An earthquake measuring 7.9 on the Richter scale struck the Kachchh region in northwestern Gujarat at 8:46 am on January 26th, 2001; there was significant loss of life and property, and people all around the India felt it.

The destruction reported by the government at that time included: 18,253 human deaths, 166,836 injured people, 7904 destroyed villages in 21 districts of Gujarat, 332,188 destroyed houses and 725,802 damaged houses of varying degrees. The peak ground acceleration of 0.11 g was recorded at the Passport Office Building in Ahmedabad, about 230 km from the epicenter.

Earthquake's effects on telecommunication towers:

Telephone communications suffered serious disruption during the earthquake. In Kachchh, most communication cables were damaged. The alternative mode of communication was a satellite phone service, which was used for about 16 hours following the disaster. Field measurements showed that although at first it seemed the damages were due to severe ground motion, later investigation showed that most of the damages were exacerbated because of a poor quality of engineering and construction.

*Figure 1. Destruction outside the Communications Center for Kachchh District, Gandhidham, March 2, 2001, with tower remained standing (*Ravi Mystry et al., 2001).

2.2. 2003 Bam earthquake (Iran)

Earthquake at a glance:

On 26th December 2003 a large magnitude 6.6 Mw earthquake struck the city of Bam, located approximately 1000 km southeast of Tehran, at 5:26 am. Although there was no record of an earthquake at the Bam fault in recent years prior to 2003, this earthquake damaged most building constructions and infrastructure of the city and surrounding villages, causing 26000 human deaths, more than 30000 injured people, and leaving approximately 75000 homeless. Since the earthquake occurred very early in the morning most people were at home and sleeping at that time, which contributed to the high number of deaths. Although the earthquake was felt around the Kerman area, the main damage was concentrated in a small area near the city of Bam, and not farther than a 230 km radius.

Earthquake's effects on telecommunication towers:

There was widespread power loss, telecommunication network disruption, and water distribution system failures. There was damage to high voltage transmission lines and towers.

Figure 2. One of the main telecommunication towers in Bam which survived the earthquake (A. Manafpour, 2003)**.**

Despite the damage, cell phones started to work within a few hours following the quake. The telecommunication disruptions were mainly caused by non-structural damage to telecom central offices which were located outside the principal area of destruction. In addition to their location, these buildings suffered less because of their relatively recent equipment and construction quality compared to other residential buildings. There were some governmental reports that represented the telecommunication central offices had primarily non-structural damage as well as damage to unanchored equipment. The most important telecom towers more or less stood strong against the quake.

Other communication towers located on roofs of some of the collapsing buildings were also damaged.

Figure 3. *Failed tower due to building collapse* (Masoud Moghtaderi-Zadeh et al., 2003).

2.3. 2004 Sumatra earthquake (Indonesia)

Earthquake at a glance:

On December 26th, 2004 at 7:59 am local time a 9.3 moment magnitude earthquake hit the northern part of Sumatra and the Andaman Sea (west coast of Northern Sumatra, Indonesia). The earthquake was the second-largest earthquake ever measured in the region and was recorded by around 1900 seismographs. It was a rare earthquake event in the history of the Indian Ocean.

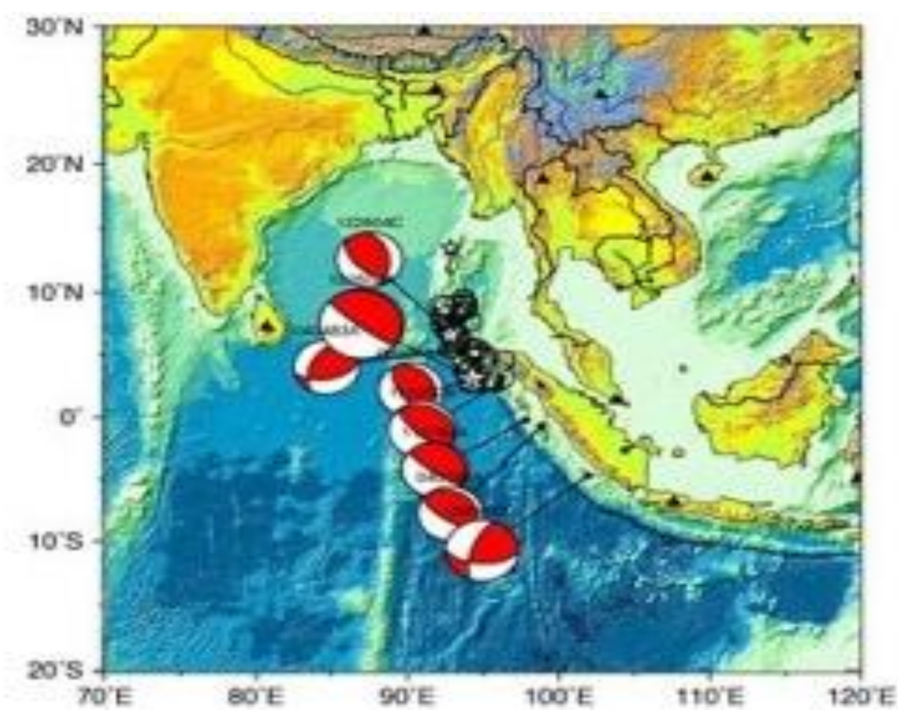

Figure 4 Location of the main shock (largest symbol) and major aftershocks of the 26 December of Sumatra earthquake 2004 (http://geology.about.com)

Earthquake's effects on telecommunication towers:

The operation of the lifeline telecommunication systems in the Andaman and Nicobar islands during the earthquake was reported as poor. Damages to several telephone exchanges caused a huge amount of disruption to telecommunication services.

Although A&N islands have land-line phone, the area near Port Blair commonly has cellular facilities and more telecommunication towers are constructed in this area. After the earthquake, only the Port Blair telecommunication tower was operational. Destruction generally occurred on telephone exchange equipment such as batteries, power plants, and satellite receivers.

In Table 2 below the percentage of surviving telecommunication towers can be found and compared to other lifeline structures.

Figure 5 One self-supported lattice communication tower in Hambantota (Indonesia) was toppled by the tsunami (Donald Ballantyne, 2004)

Table 2. Summary of damage and losses to infrastructure as a result of Sumatra 2004 earthquake (BAPPENAS, 2005).

Infrastructure	Total loss	% of total	Direct damage	Consequential losses	Public property	Private property
Transport	4984	61	3632	1352	3442	1542
Roads and land transport	4679	94	3379	1301	3137	1542
Roads	1735	35	1576	159	1635	100
Land transport	2944	59	1803	1142	1503	1442
Ports	259	5	237	22	259	0
Airport	46	1	17	29	46	0
Water and sanitation	276	3	247	29	106	170
Water supply	267	97	238	29	97	170
Sanitation	9	3	9	0	9	0
Energy	632	8	631	1	622	10
Electric power	500	79	500	0	500	0
Petroleum	132	21	131	1	122	10
Communication	203	2	176	27	123	80
Telecom	194	96	167	27	114	80
Postal service	9	4	9	0	9	0
Irrigation and flood control	2058	25	1230	829	1229	829
Immigration	543	26	543	0	542	0
Flood control	1355	74	687	668	709	646
Total	8154	100	5915	2239	5522	2631

Figure 6 Collapsed telecommunication tower as a result of Sumatra tsunami (Teddy Boen, 2004)

2.4. 2005 Kashmir earthquake (Pakistan)

Earthquake at a glance:

The October 8^{th}, 2005 Kashmir earthquake measured 7.6 on the Richter scale , had a focal depth of 26 km, and occurred at 8:50 am. Numerous aftershocks happened which were as strong as 4.0 to 6.0 Richter scale. These aftershocks happened at about 150 km away from the tectonic line of continent-to-continent convergence.

Earthquake's effects on telecommunication towers:

The telecommunication network suffered extensive damage and equipment had to be replaced. Responsibility for the provision, operation and maintenance of telecommunications networks rested with the Special Communications Organization (SCO) in AJK (Azad Jammu and Kashmir) and the Northern Areas.

Quick progress was made to retrofit the communication networks. For instance in AJK 36% of exchanges and 18% of lines were affected but were made operational within a week. Similarly, in NWFP(North West Frontier Province) 15% of exchanges and 10% of lines were affected but were restored within two weeks.

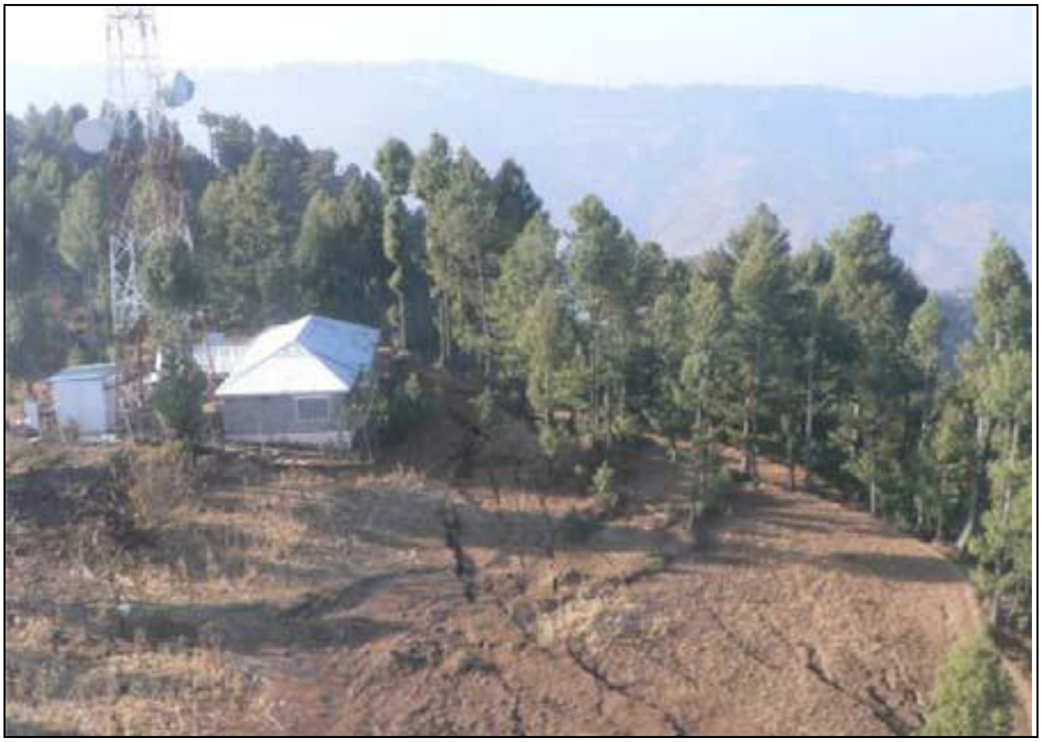

Figure 7 Lateral soil failure spreading at Dana hilltop in the vicinity of the SCO-Tower (Kashmir Earthquake) (Jean F. Schneider, 2008)

2.5. 2008 Sichuan earthquake (China)

Earthquake at a glance:

The 2008 Sichuan earthquake was a deadly earthquake of 8.0 Ms and 7.9 Mw that occurred at 2:28 PM on Monday, May 12th, 2008 in the Sichuan province of China, killing an estimated 68,000 people.

Effects on telecommunication towers:

Half of the wireless communication service in Sichuan province was lost, and telecommunications in Wenchuan and four nearby counties were cut off. "China Mobile" which is the largest telecommunications service provider in China experienced severe disturbances because of the dysfunction of nearly 2,300 base stations. The post-earthquake emergency response provided some emergency telecommunication vehicles, many equipped with satellite communications facilities.

Government efforts during the first week following the earthquake restored electric power and telecommunication services in priority. Figure 1-8 presents one collapsed telecommunication system during the Sechuan earthquake.

Figure 8 Collapsed telecommunication tower in the Sechuan2008 earthquake (Aiping Tang et al., 2010)

2.6. 2010 Chile earthquake

Earthquake at a glance:

On February 27^{th} 2010, a 8.8 Richter scale earthquake hit the central part of Chile (the most populated area of the country with 80% of Chile's population) at 3:34 am. The earthquake was the fifth strongest earthquake in recorded history and was considered to be a "mega earthquake". The earthquake's epicenter was located at 35.909°S, 72.733°W and had a plate rupture of about 550 km by 150 km. The epicenter was located 335 km SW of the capital city of Santiago and 105 km NE of the coastal city of Concepcion. Many aftershocks were felt over the following months, including 130 such quakes that had a magnitude of 6 or higher that followed within the weeks afterwards.

According to the Chilean Deputy Interior Secretary report on April 7^{th} 2010, 1.8 million people were affected in Araucania, Bio-Bio, Maule, O'Higgins, Santiago and surrounding areas, and Valparaiso, 521 people were killed, 56 went missing, about 12000 injured, 800,000 displaced and at least 370,000 houses, 4,013 schools, 79 hospitals and 4200 boats damaged or destroyed by the earthquake and tsunami in the Valparaiso-Concepcion- Temuco area. The total cost of the disaster was estimated at 30 billion US dollars.

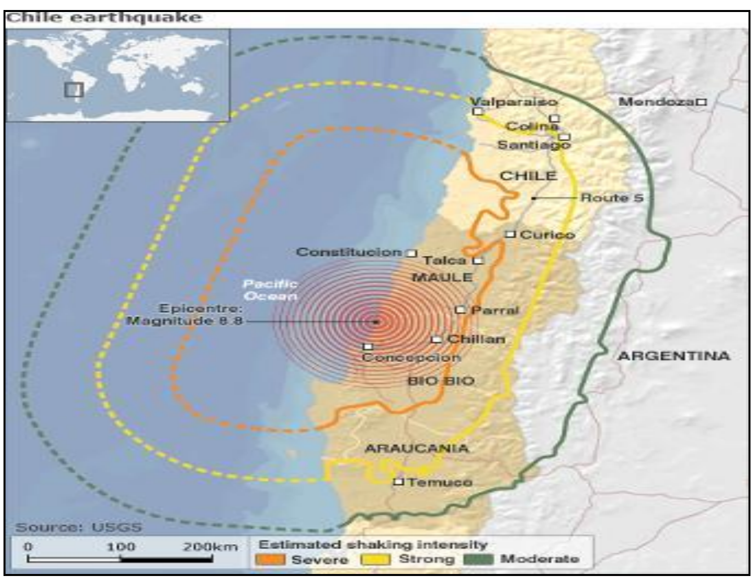

Figure 9 Map of Central Chile earthquake ([http://www.asce.org)](http://www.asce.org)

Earthquake's effects on telecommunication towers:

According to the American TCLEE (Technical Council on lifetime Earthquake Engineering) report, all telecommunication service providers, both landline and wireless services, suffered severe disruption because of problems such as: power outages, equipment failures, antennae damage, building failures, loss of reserve power in most network facilities in the affected areas and fallen antennae from towers, which was one of the most common problems. Damages in some regions reached a dysfunction rate of about 70 % to 80 %, including problems with their equipment such as antenna damage. The figure below shows that landlines were repaired slightly sooner than wireless services in the Biobio region.

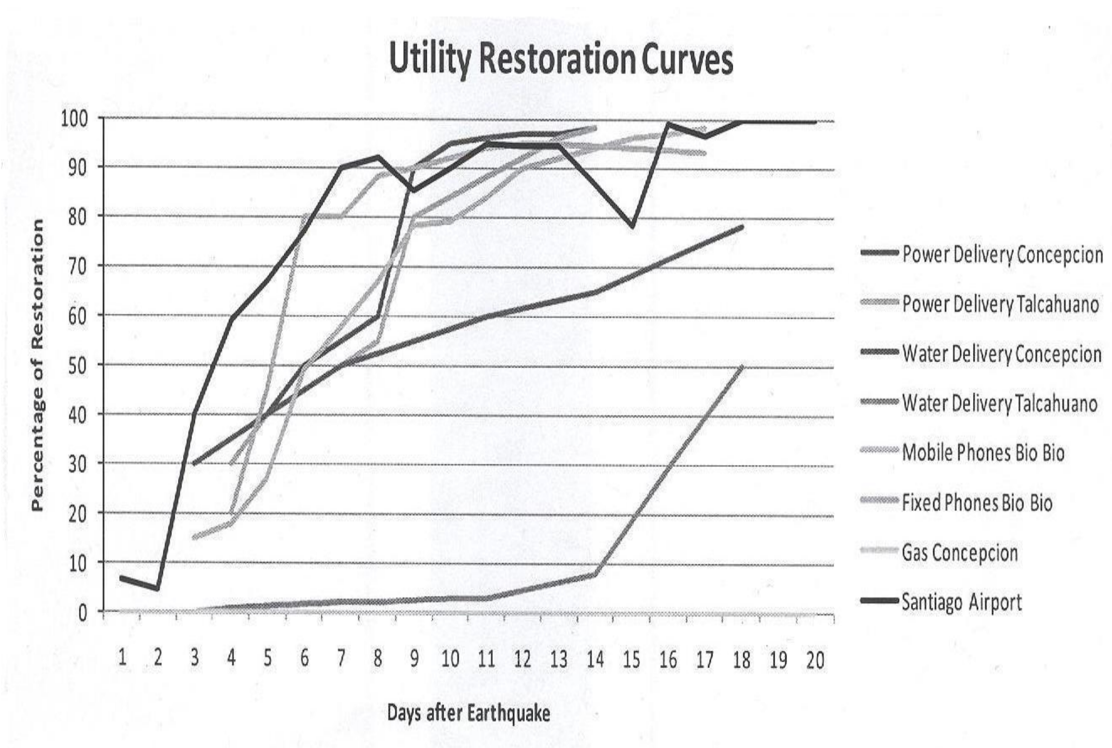

*Figure 10 Restoration curve (modified TCLEE). (*N.L. Evans and C. McGhie, 2010)

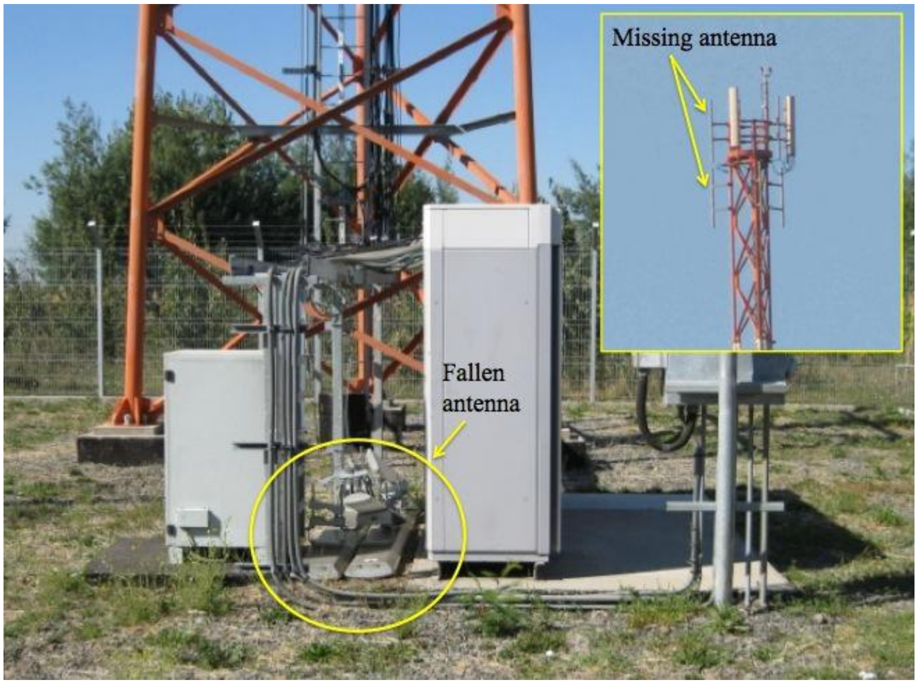

Figure 11 Fallen antenna Chile 27 February 2010 (Peak ground acceleration of 0.65g) (TCLEE web report)

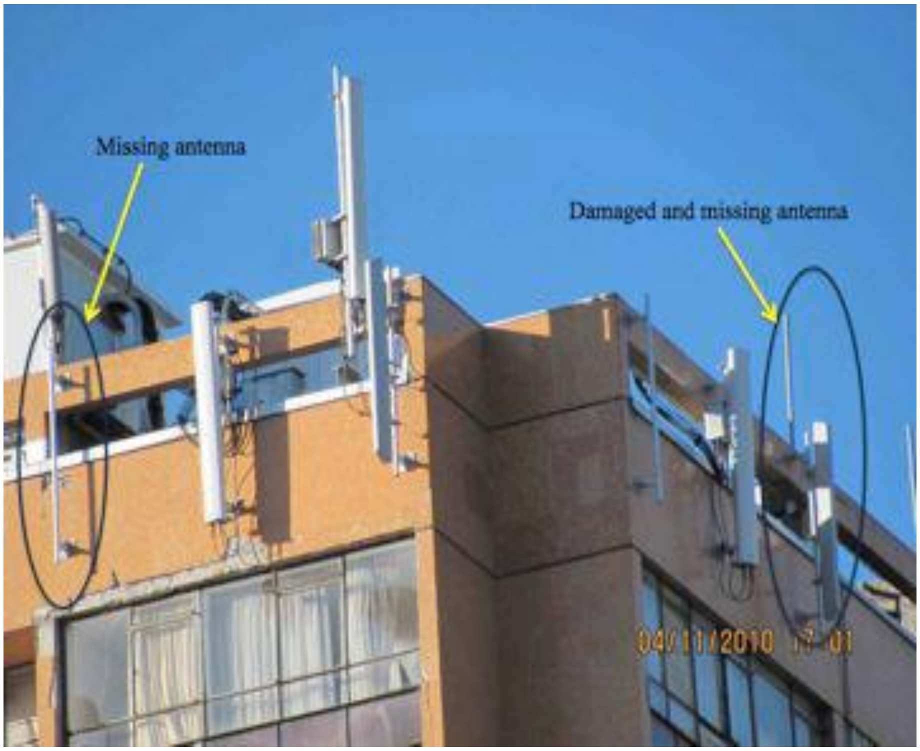

Figure 12 Chile 2010 – Rooftop mounts(TCLEE web report)

2.7. 2010 Haiti earthquake

Earthquake at a glance:

On January 12th 2010 at 16:53 local time, 7.0 magnitude earthquake with an epicenter near the town of Léogâne, approximately 25 km west of Port-au-Prince, Haiti's capital, struck Haiti.

For the following 12 days more than 52 aftershocks measuring 4.5 or greater were recorded. Haitian government reports estimated that around 316,000 people had died, 300,000 had been injured and 1,000,000 made homeless. International agencies, including the United States Agency for International Development, have suggested that the total number of deaths is much lower than previously reported, and is somewhere between 46,000 and 220,000, with around 1.5 million to 1.8 million homeless. The government of Haiti also estimated in their report that 250,000 residences and approximately 30,000 commercial buildings had either collapsed or were damaged beyond repair.

Earthquake's effects on telecommunication towers:

The main reason for the huge amount of damage in Haiti was due to the lack of concern for considering seismic events during the construction of residential housing and multi-story buildings in downtown Port-au-Prince. None of these structures were built with awareness of the most basic principles of seismic design and construction. This showed that there is a lack of proper building code regulations and licensing for architects, engineers, or contractors in Haiti, especially on the topic of seismic design. This happened because engineers began using codes from different countries such as France (Béton Armé aux Etats Limites(BAEL)), or the gravity load provisions from the American Concrete Institute code (ACI318) without paying attention to whether or not the codes contained any consideration for seismic design.

Results of the earthquake:

- Technical buildings damaged (Digicel)
- Antennas, or hosting buildings, damaged
- No electricity
- Telecommunication situation:
- Poor GSM (Global System for Mobile) connectivity (Digicel down, Voila and Haitel saturated)
- SMS worked but uncertain reliability
- Data connectivity available with the MINUSTAH at the LogBase

Figure 13 Partially collapsed telecom switch building as a result of Haiti earthquake
(http://mrpengineering.com/haiti_images.htm#thumb)

Figure 14 Antenna damaged in Carrefour as a result of Haiti earthquake (Adele Waugaman et al., 2010)

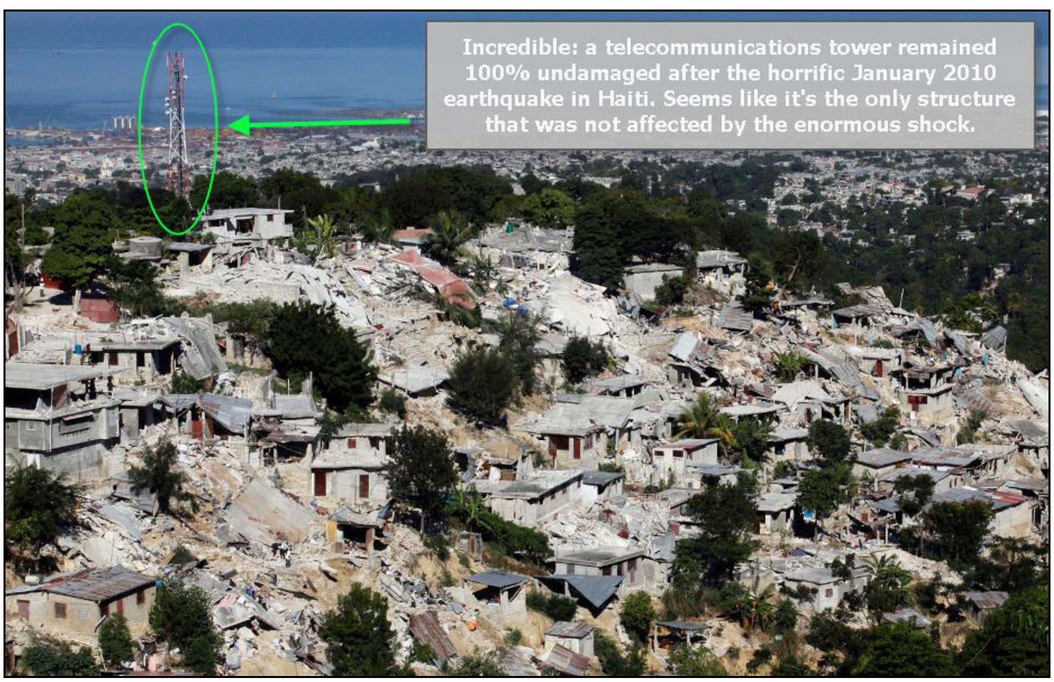

Figure 15 A telecommunication tower remained 100% undamaged after the January 2010 Haiti earthquake (Adele Waugaman et al., 2010)

2.8. 2010 New Zealand earthquake

Earthquake at a glance:

On 4th September 2010 at 4.36am, a 7.1 magnitude earthquake hit Christchurch and wider Canterbury in New Zealand. The earthquake was felt throughout the South Island and the lower North Island. The epicenter was located near Darfield, 40km west of Christchurch City center at a depth of 10 km. The earthquake ranked among the strongest ground-shaking quakes in New Zealand to that date. (PGA=0.35g).

Earthquake's effects on telecommunication towers:

Steel towers are the main type of mobile sites with height generally between 15 m to 20 m. In addition to mobile sites, some rural sites also use steel guyed masts for supporting their antennas. These types of towers generally survived the quake although some non-significant damages because of liquefaction affected their foundation.

The earthquake caused loss of electricity to most of Christchurch city; however, the exchanges were able to continue working on battery power.

In some mobile sites there was limited access to carry out restoration work because of the need to access the rooftop towers from the building. There are two major cell phone operators in the Christchurch area: Telecom and Vodafone, and both experienced similar problems, such as:

- They ran out of reserve battery power at base Transceiver Stations (BTSs, also called cell sites)
- Call congestion
- Cellular network tower out of plumb due to soil liquefaction

• Underground cable damage due to liquefaction-induced permanent ground deformations.

Two cell phone towers tilted because of liquefaction. The towers were out-of-plumb by 2° to 5°. Since these rotations did not cause any considerable effect on the serviceability of the towers, no effort was made for repairing them within the first 6 weeks after the earthquake. In some cases, fixed telecommunication lines remained in service. Although there was no significant problem due to the tower's damage, people nonetheless experienced service problems. Because many people only have mobile phones, they were unable to maintain communication while there was power loss.

Figure 16 Cellular antenna tower out of plumb due to ground deformation as a result of New Zealand earthquake (JM Eidinger, 2012)

It is noteworthy that no structural damages to telecommunications structures have ever been reported for earthquakes with peak ground acceleration less than about 0.7g.

Devastation has been widespread in several recent earthquakes, but the most severe effects on telecommunication towers were mainly the result of rooftop towers collapsing because of building collapse, tower failures on ground (especially cellular towers) as a result of lack of earthquake-resistant design standards, and ground tower failures due to soil failures.

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