Flash Report on Damage Caused in Mexico City, Mexico, by the 2017 Puebla-Morelos Earthquake

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ABSTRACT

An earthquake with a moment magnitude (*Mw*) of 7.1 occurred at 13:14 CDT (18:14 UTC) on September 19, 2017, in the city of Puebla in Mexico. A damage survey was conducted in the affected area from November 18 to 21 by a team from the National Research Institute for Earth Science and Disaster Resilience. This paper outlines the findings of the survey in terms of the various aspects of the earthquake that affected Mexico City and surrounding areas. It was observed that the main damage was to masonry reinforced concrete buildings and the most heavily damaged structures correspond to areas underlain by soft soils 10–20 m in thickness. Comparison of estimated acceleration distribution for periods of 1 s corresponds to 8–12 story buildings, and these period areas correspond to heavily damaged structures. We show improvement of disaster resilience technology.

Key words: *2017 Puebla-Morelos Earthquake, Mexico City, Puebla, earthquake disaster, disaster resilience technology*

1. Introduction

An earthquake with a moment magnitude (*Mw*) of 7.1 occurred at 13:14 CDT (18:14 UTC) on September 19, 2017, in the city of Puebla, Mexico. The epicenter was in central Mexico (18.58° N 98.40° W) at a depth of 51 km (USGS: U.S. Geological Survey). The earthquake was officially named the 2017 Puebla earthquake because the epicenter was located beneath the city of Puebla, and the shallow depth resulted in it being highly destructive.

Statistics provided by The National Coordinator of Civil Protection of the Ministry of the Interior indicate that 369 casualties were recorded on October 5. Mexico City had the highest number of deaths (228), while 73 deaths were recorded in Morelos. A total of 45 deaths were recorded in Puebla, 13 in the State of Mexico, 6 in Guerrero and 1 in Oaxaca. **Fig. 1** shows the maps of Mexico City (CDMX) and surrounds showing the survey routes followed (red lines).

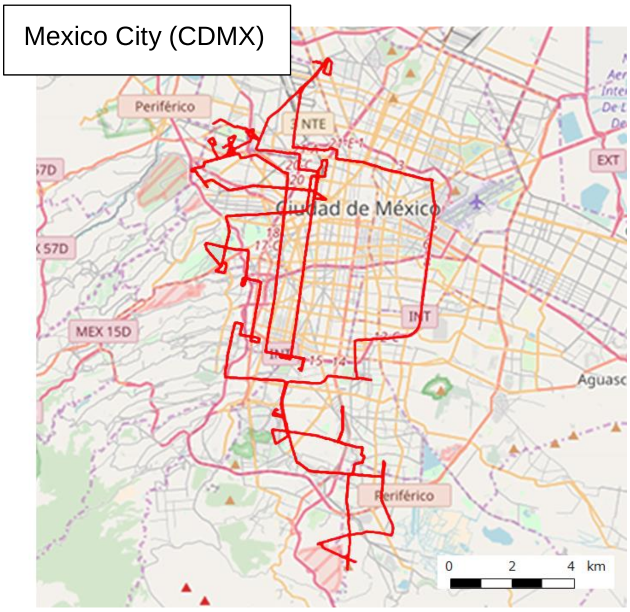

Fig. 1 Maps of Mexico City (CDMX) and surrounds showing the survey routes followed (red lines) (OpenStreetMap https://www.openstreetmap.org/).

2. Strong Motions

2.1. Comparison of the 1985 and 2017 earthquakes

Fig. 2.1 shows a comparison of the Fourier spectra of different heights at sites CU (rocky ground) and SCT (soft ground) for the 1985 earthquake (blue) and the 2017 earthquake (red). According to UNUM report [1], Peak Ground Acceleration (PGA) in 1985 was 160 Gal, while in 2017 PGA was 91 Gal. Peak Ground Acceleration (PGA) is a measure of the severity of ground shaking. However, accelerations in the soil during the 2017 earthquake were most likely greater than those recorded in 1985 because of the complex movement pattern and high spatial variability.

In 1985, the ground response was amplified up to 7–8 times at building sites located on the lake bed in contrast to those located on hard rock in Mexico City. During the 1985 earthquake, PGA at the soft soil site (SCT) was significantly higher than at the rocky site (CU).

2.2. Comparison of seriously damaged structures from the 1985 and 2017 earthquakes

Fig. 2.2 shows a comparison between seriously damaged structures from the 2017 earthquake (red) and the 1985 earthquake (blue). The thickness of soft soils is also shown; the base map derived from Martinez Gonzalez, Jose (2015) [2]. The seriously damaged structures in 2017 were concentrated in areas with 10–20 m soil thickness, while seriously damaged structures from 1985 were concentrated in areas with 30–40 m soil thickness.

Fig. 2.3 shows a comparison between seriously damaged structures from the 2017 earthquake (red) and the 1985 earthquake (blue). Periods were measured using microtremor measurements, with the base map derived from Reinoso, E. and Lermo, J. (1991) [3]. The seriously damaged structures in 2017 were concentrated 1–2 s areas, while seriously damaged structures in 1985 were concentrated in 3–4 s areas.

Fig. 2.4 shows transfer functions obtained from 10 m, 20 m and 40 m within the simplified soil profiles and sedimentary layers from one-dimensional analysis of the dominant frequency. The Vs values of the ground were set from Facciolia and Flores (1975) [4] to FAS, which is normally consolidated clay, and DP, which is a sand layer

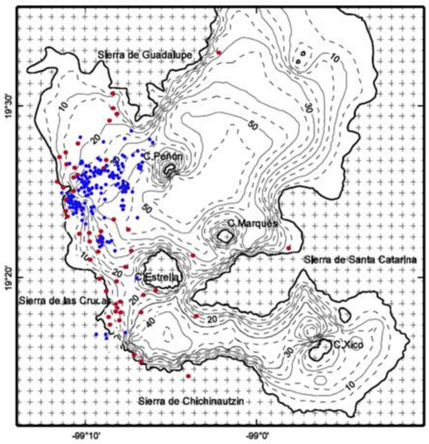

Fig.2.2 Map showing the thickness soft soils and damaged structures (base map from Martinez Gonzalez, Jose, 2015) [2].

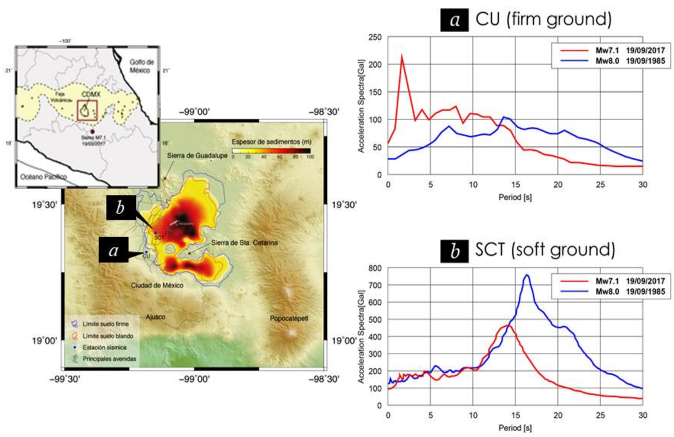

Fig. 2.1 Comparison of the Fourier spectra of different heights at sites (*a*) CU (firm ground) and (*b*) SCT (soft ground) for the 1985 earthquake (blue) and 2017 earthquake (red)

(UNAM, Sep. 23, 2017) [1].

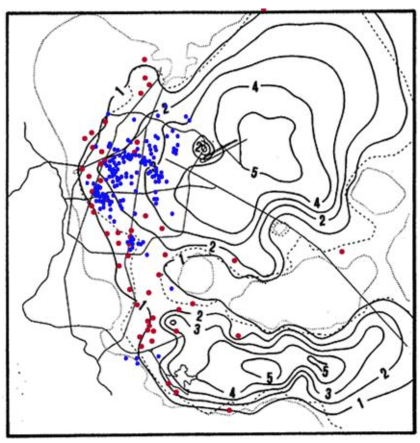

Fig. 2.3 Comparison between seriously damaged structures. Periods were measured using microtremor measurements, with the base map derived from Reinoso, E. and Lermo, J. (1991) [3].

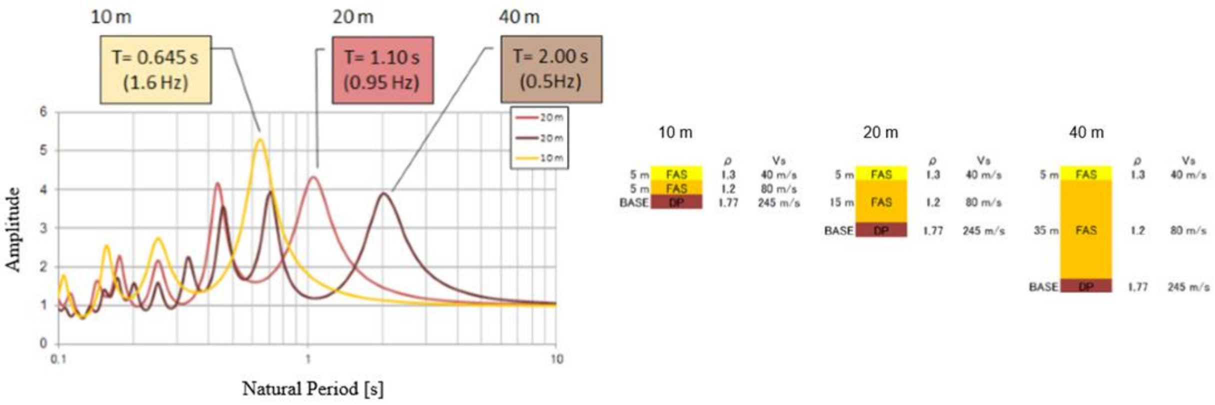

Fig. 2.4 Transfer functions were obtained from 10 m, 20 m and 40 m in the simplified soil profiles.

including gravel.

In the 10 m case, the dominant period of transfer functions is 0.645 s (1.6 Hz) and the amplification of ground motion is 5.3. In the 20 m case, the dominant period of transfer functions is 1.1 s (0.95 Hz) and the amplification is 4.3. In the 40 m case, the dominant period of transfer functions is 2.0 s (0.5 Hz) and the amplification is 3.9. In the 1985 earthquake, which had long-period components of earthquake motion, caused high amplification in soft soils. However, in the 10 m case, which is shallow and segmented, the higher contrast *Vs* value of segmented layers and the basement contributed to increasing the amplification of ground motion in the 2017 earthquake, which had short-period components of earthquake motion.

3. Survey Areas in Mexico City (CDMX)

3.1. Buildings designated for demolition

In Mexico, seismic diagnosis of buildings is undertaken by government. Based on the judgment following the 2017 earthquake, it was decided that 13 buildings would be demolished.

After obtaining approval from the Emergency Committee, the demolition work started on October 10, 2017 in the CDMX. There are 13 buildings already confirmed for demolition, since it was specified that in the first three cases, the state will use surveyors and an engineering team to determine the demolition method. These 13 buildings were selected as survey points in this study as shown in **Figs. 3.1** and **3.2**).

Fig. 3.3 shows the demolition level structures with the acceleration distribution for the 1.0 s period estimated from the roofs of buildings. All structures are within the 1.0 s acceleration period area (base map from UNAM, 2017) [5].

3.2. Tlatelolco Complex area

The Tlatelolco Complex area was heavily damaged in the 1985 earthquake. For example, the 14-story RC Nevo Lion building in the Tlatelolco Complex, which included a north side and southern wing connected by an Expansion Joint, suffered a collapse of the two north side buildings that resulted in many casualties. After the 1985 earthquake, the Nevo Lion was renovated with new wings and walls with JICA (Japan International Cooperation Agency) support (**Fig. 3.4**).

We visited the Tlatelolco Complex area to verify this renovation. Structures designed and built with earthquake-resistance showed no discernible damage after the 2017 earthquake based on external inspection. **Fig. 3.5** shows the lack of externally visible damage evident in the renovated Tlatelolco Complex after the 2017 earthquake.

3.3. Damaged RC housings

Two adjacent housing blocks were built in the same period in 1970, as shown in **Fig. 3.6**, and both buildings will be demolished. However, the building on the right was heavily damaged and the parking lot on the first floor collapsed. The housing block on the left was inspected, and found to have higher quality concrete than the right block. Also, the building column construction used hoops/stirrups at a 45 cm pitch, while the hoops/stirrups were of very poor quality in the housing block on the right.

3.4. Was the piloty structure damaged?

According to National Population Council, the estimated population for the metropolitan section of Mexico City in 2009 was approximately 8.84 million people. According to the most recent definition agreed upon by the federal and state governments, the Greater Mexico City population is 21.3 million people, making it the largest metropolitan area in the Western Hemisphere, the tenth-largest agglomeration, and the largest Spanish-speaking city in the world. Most housing developments are constructed with a dense overlapping structure (**Fig. 3.7**), and the first floor has a piloty space. The piloty structure of this space is typically weakly built, and they have collapsed in many housing (**Fig. 3.8**).

3.5. Steel braces and concrete columns

In Mexico City, braces are installed on buildings to decrease the risk of blocks falling off, or bricks in the wall falling out of the plane of the building. Thus, a gable wall between the brace is used to sustain a resilience method. Buildings reinforced with steel braces are shown in **Fig. 3.9** and typical diagonal reinforced concrete bracing with masonry infill is shown in **Fig. 3.10**.

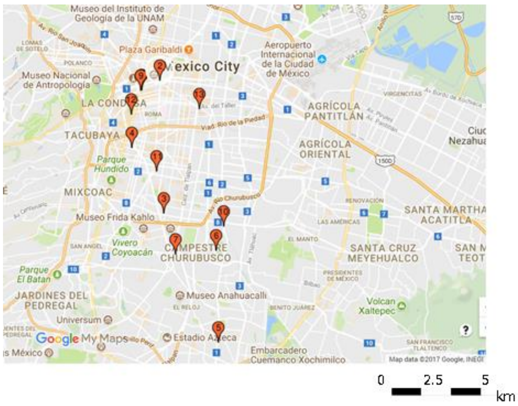

Fig. 3.1 Map showing the 13 buildings designated for demolition (Google Maps®)

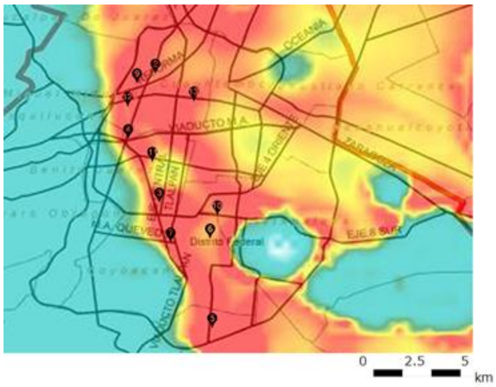

Fig. 3.3 Map showing the distribution of the 13 structures designated for demolition level within the 1.0 s acceleration period area.
(base map from Martinez Gonzalez, Jose, 2015).

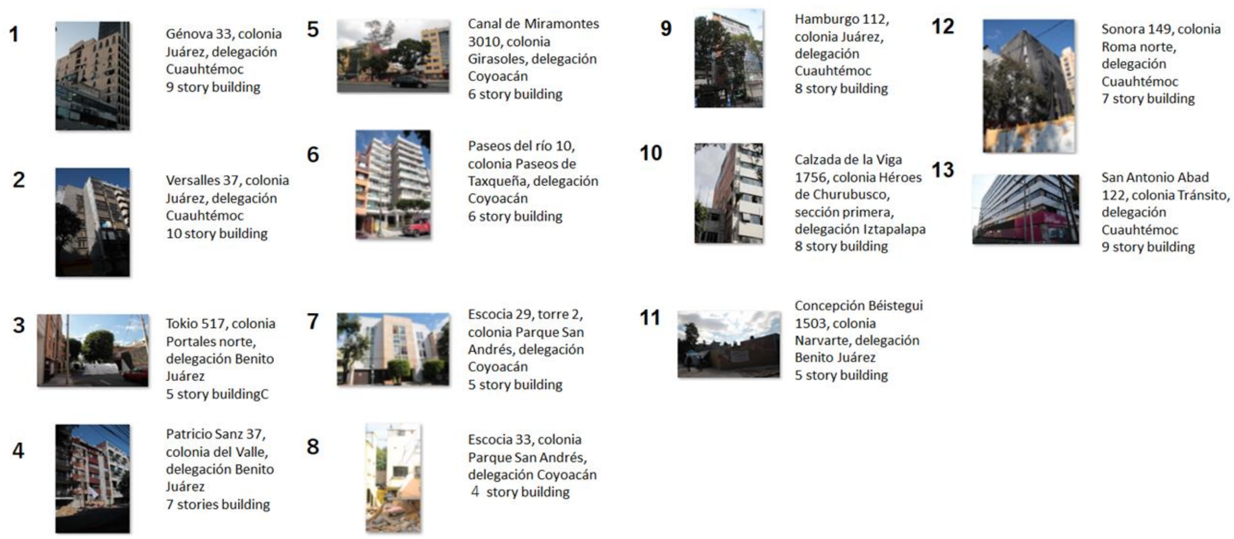

Fig. 3.2 Photographs of 13 buildings designated for demolition (photo taken by T. Ohsumi and Y. Dohi on November 19, 2017)

Fig. 3.4 Renovated Tlatelolco Complex, after the 1985 earthquake. (Courtesy of Prof. Nakano with Tokyo Univ.)

Fig. 3.5 Photograph showing the lack of externally visible damage evident in the renovated Tlatelolco Complex after the 2017 earthquake. (photo taken by T. Ohsumi on November 19, 2017)

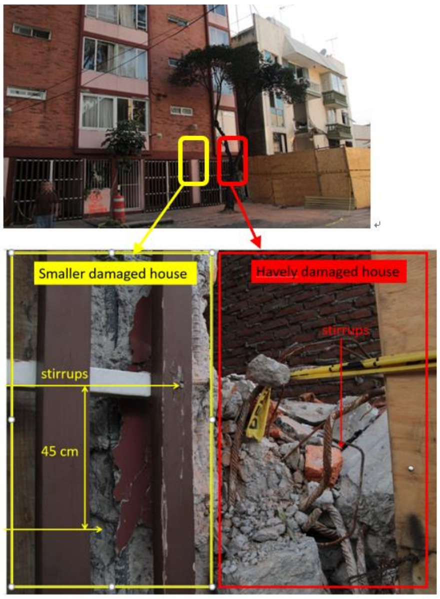

Fig. 3.6 Comparison of damage to two housing blocks. Note the heavily damaged housing on the right with poor quality hoops/stirrups (photo taken by T. Ohsumi at November 19, 2017)

Fig. 3.7 Typical housing in Mexico City.
(photo taken by T. Ohsumi on November 21, 2017)

Fig. 3.8 Piloty space crashed and the car were crushed.
(photo taken by T. Ohsumi on November 19, 2017)

Fig. 3.9 Photographs of buildings reinforced with steel braces.

Fig. 3.10 Masonry building which was reinforced with concrete columns.
(photo taken by T. Ohsumi on November 18-19, 2017)

3.6. Latin American Tower

The Latin American tower was inaugurated on April 30, 1956. It was designed by Adolpho Zeevaert, in consultation with N. Newmark and Leonardo Zeevaert. The Latin American Tower is a source of pride for the inhabitants of the Mexico City metropolis, as it broke several engineering records during its construction using Mexican technology. The structure survived the 1957, 1978, 1979, 1985 and also the September 2017 earthquakes with only minor nonstructural damage. A memorial plate was installed in the Latin American Tower (**Fig. 3.11**) and it describes how the Tower has been able to sustain multiple episodes of strong seismic forces. **Figs. 3.12** and **3.13** show the seismometer and deformation meter of the tower, respectively. Deformation is registered as the proportion of movement within a range of permissible values in the tower. **Fig.3.14** shows the Latin American tower technology.

Fig. 3.11 Memorial plate in the Latin American Tower. (photo taken by T. Ohsumi on November 21, 2017)

Fig. 3.12 Seismometer in the Latin American tower. (photo taken by T. Ohsumi on November 21, 2017)

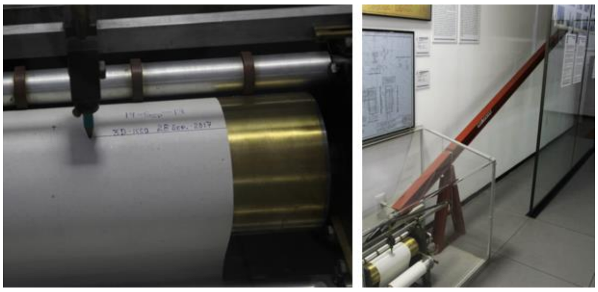

Fig. 3.13 Deformation meter in the Latin American Tower. (photo taken by T. Ohsumi on November 21, 2017)

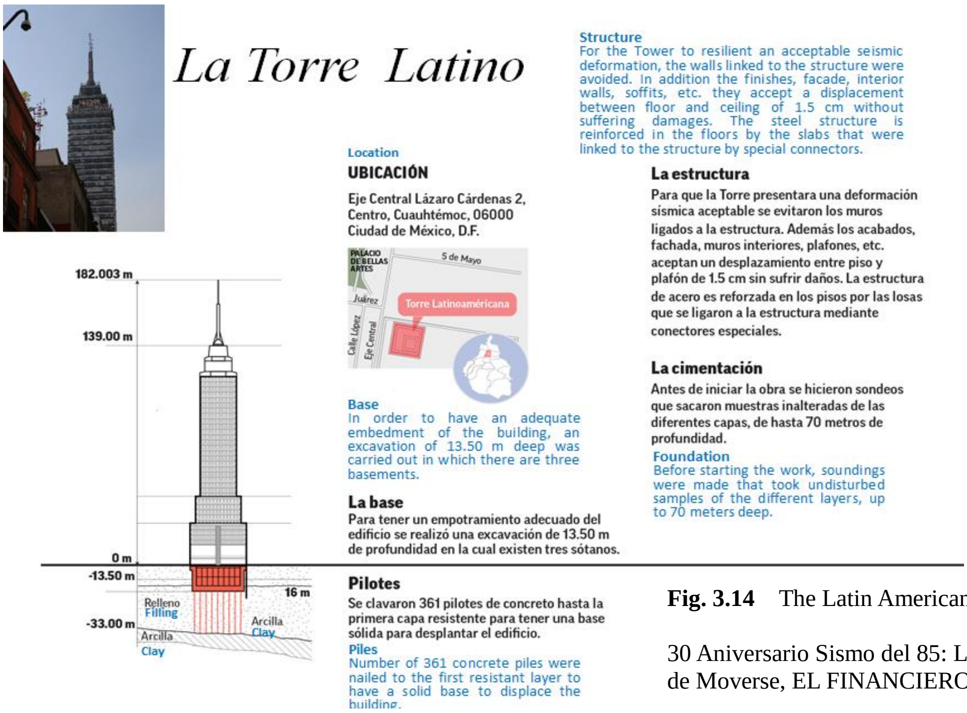

Fig. 3.14 The Latin American tower technology.

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4. Transmission of Horizontal Forces in an Earthquake

The elements within a building that are most affected during an earthquake are the structural elements because of the forces that are transmitted through them.

4.1. What is a structural system?

It is important to note whether structures are composed of several elements, and have the function of supporting the loads that act on them seismically, by transmitting them into the ground.

4.2. Type of Cracks

The engineer Yoshio Joel Salinas, general director of T22 Coordination and Architecture, indicated that after the earthquake it is necessary to detect the types of cracks evident in buildings in terms of their relative risk of further failure (**Fig. 4.1**).

5. Rescue Technology

5.1. Anything goes to find life: dogs and scanners

Scanning technology has progressed significantly since 1985, and is used by the Armed Forces (such as SEDENA in Mexico, Secretaría de la Defensa Nacional) to find people trapped under rubble. SEDENA uses wall-mounted scanners to search for people in collapsed structures and works in the same way as radar. The equipment sends out a signal to a specific point, and returns and informs if there is no vibration. Any movement, even that of a finger, is recognizable by this device. The wall-mounted scanners have a range of up to 40 m, depending on the type of wall. It is able to determine the depth and location of buried individuals. All branches of SEDENA where collapses occurred have a team equipped with these scanners.

In addition, the “canine binomials” are important additions to the rescue efforts, and consist of a trained rescue dog and a handler. The relationship between the two, and with the individual being rescued, is one of trust and empathy. The dogs are able to detect even faint odors of buried individuals and their physical dimensions allow them to travel through smaller spaces than humans would be able to. Navy’s staff is responsible for training the dogs for 12 to 14 months, and they are employed in rescue tasks for six to seven years. **Fig. 5.1** shows the scanning technologies, which are described in detail below.

1) Uwb Detector: These detectors use radio technology at

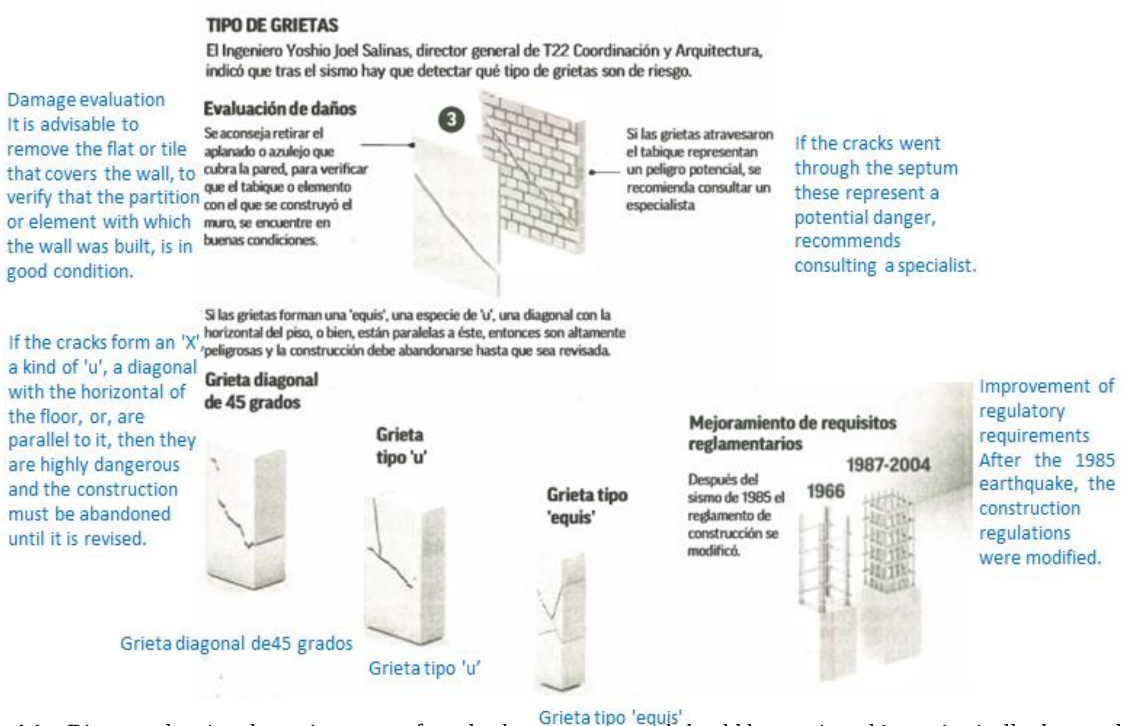

Fig. 4.1 Diagram showing the various type of cracks that can occur and should be monitored in a seismically damaged structure (courtesy of EL FINANCIERO, September 26, 2017)

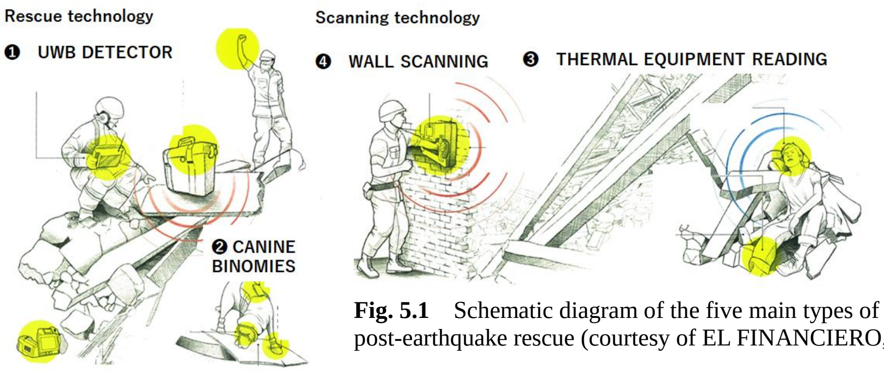

Fig. 5.1 Schematic diagram of the five main types of scanning technology used in post-earthquake rescue (courtesy of EL FINANCIERO, September 22, 2017)

bandwidths >500 MHz (UWB) to probe beneath the surface of the debris for movement. The device detects even small movements of the chest caused by breathing. It locates victims by detecting movements up to 30 m away. The rescuers do require absolute silence during detection to accurately follow meaningful signals beneath debris.

2) Canine Binomies: These are the partnered dog and trainer, both prepared to search for people under rubble. A Harness may be used if they require it, and glasses help protect the dog’s eyes in case of smoke, dust or other substances. Boots are also used to help protect their legs. Frida is a dog that belongs to the canine section of the Mexican Navy Secretariat, and she has managed to rescue 52 persons and has collaborated in rescue work in Honduras, Ecuador and Haiti.

3) Thermal Equipment Reading: Thermal equipment is used to locate people beneath the rubble. The rescue of those who are buried in debris without injuries and who can move freely is relatively easy with this method. In the event that an individual is injured or trapped a tourniquet can be used and vital signs are checked, followed by their recovery.

4) Wall Scanning: The wall scanning equipment allows users to observe an area from behind a wall. The scanner detects micro-shocks caused by breathing, heartbeat or physical gestures of people trapped.

6. Findings

Based on the study presented, and the survey results, the following conclusions can be drawn:

Heavily damaged structures in the Mexico City area related to the 2017 earthquake are underlain by areas consisting of soft soils 10–20 m in thickness.

Comparison of the estimated acceleration distribution for the 1 s period corresponds to 8–12 story buildings. These period areas correspond to areas of heavily damaged structures related to the 2017 earthquake.

In the 10 m case, which is shallow and segmented, the higher contrast Vs value of segmented layers and the basement contributed to increased amplification of ground motion in the 2017 earthquake, which had short-period components of earthquake motion.

In Mexico City, minor damage was evident in urban buildings with modified improvement of regulatory requirements in terms of construction that were in place after the 1985 earthquake. Conversely, buildings not subject to these regulatory requirements were more heavily damaged.

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