Post-Earthquake Safety Evaluation of Buildings in Portoviejo, Manabí Province, following the M_w7.8 Ecuador Earthquake of April 16, 2016

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Abstract. This paper describes the post-earthquake safety assessments conducted by the European Union Civil Protection Team (EUCPT) following the M_w 7.8 Ecuador earthquake of April 16, 2016. The mission of the structural engineers within the EUCPT took place from April 22 to May 7, 2016. Several activities were performed: (i) rapid post-earthquake safety evaluations of buildings, (ii) demolition verification, (iii) safe road access, and (iv) detailed post-earthquake safety assessments of critical buildings. Despite the small number of structural experts, more than 1,000 buildings were inspected in Portoviejo and approximately 150 in Pedernales. Several lessons were identified during this mission, including the need of embedding local experts in foreign teams and the importance of having preparedness programs on post-earthquake assessment both for technicians and emergency managers. The efforts of the EUCPT benefitted largely from a Disaster Risk Reduction (DRR) pilot project which was underway at the time of the earthquake. While the project was not yet completed, such investment in DRR benefitted the disaster response efforts, even in areas which were not directly involved in the program.

Keywords: Ecuador, Earthquake, Safety Evaluations, Buildings, Disaster Risk Reduction

1. The event

Ecuador lies above the destructive plate boundary where the Nazca plate is subducting beneath the South American plate. The convergence rate between the plates in Ecuador is about 65 millimeters per year [1]. Ecuador has a history of large earthquakes related to this subduction zone (Figure 1). Seven M_w7 or greater earthquakes have occurred within 250 km of the 2016 event since 1900. According to USGS [2] in 1906 a M_w8.3 earthquake nucleated 90 km to the northeast of the April 2016 event and ruptured over a length of approximately 400-500 km. In 1942 a M_w7.8 earthquake occurred 43 km south of the April 2016 event. The April 2016 earthquake is at the southern end of the approximate rupture area of the 1906 event. A shallow, upper crustal M_w7.2 earthquake 240 km east of the April 2016 event occurred on March 6th, 1987. Ye et al. [3] pointed out the similarity of the 1942 and 2016 events.

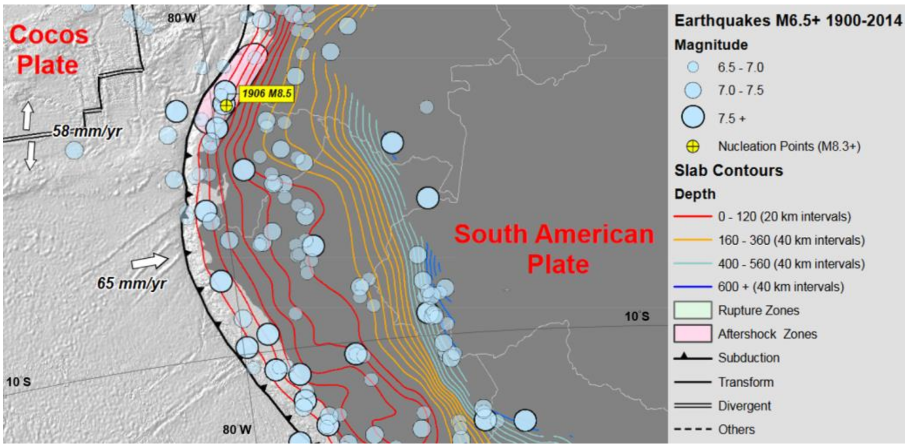

Figure 1. Subduction zone, plate movements and earthquakes from 1900 to present with M>6.5, (modified from USGS)

The 2016 Ecuador earthquake occurred on April 16 at 18:58 local time with a moment magnitude, M_w, of 7.8 and a maximum Mercalli intensity of VIII [4]. The very large thrust earthquake was centred approximately 27 km from the towns of Muisne and Pedernales, in a sparsely populated part of the country, and 170 km from the capital Quito, as seen in Figure 2 and other two strong aftershock of M_w6.2 occurred the morning of April 20 at 03:33 local time, with the epicentre in the same area, 20 km west of Muisne at a depth of 15.7 kilometers [5].

Most of the instruments that recorded ground motions are part of the RENAC (National Network of Accelerometers or Red Nacional de Acelerógrafos in Spanish) that is managed and maintained by Ecuadorian Geophysical Institute from the National Polytechnic School. Recordings are presented in Singaucho et al. [6]. The strongest motion with PGA=1.41 g was recorded in the EW direction at PDNA station in Pedernales, at an approximate distance of 20 km from the fault. At the same station, the NS component recorded a PGA=0.83 g. Another station in Pedernales, PDNS, at similar distance from the fault recorded 1.03 and 0.94 g in the EW and NS components, respectively. Portoviejo station (APO1) recorded 0.31g in the EW component and 0.37 g in the NS component, considerably lower than in Pedernales.

Widespread damage was caused across Manabí province as a result of the main shock on April 16. Regions of Manta, Pedernales and Portoviejo accounted for over 75 percent of total casualties. 661 people were killed, 6,274 injured and 28,678 displaced [7]. Approximately one month after the April 16 event, the strongest aftershocks occurred, with a M_w6.7 and M_w6.8 recorded May 18 with epicentres at 37 and 24 km, respectively, north-west of Quinindé, in the province of Esmeraldas as shown in Figure 2. These aftershocks, felt in the capital Quito and Colombia, resulted in additional damage, 85 people injured and one death [8]. Overall, the Ecuadorian Geophysics Institute recorded 1,575 aftershocks, 8 with magnitudes greater the 6 and 35 with magnitudes greater than 5 on the Richter scale, between April 16 and May 20. Final casualties were reported as 663 people killed, 9 missing, 6,274 injured and 28,775 displaced [9].

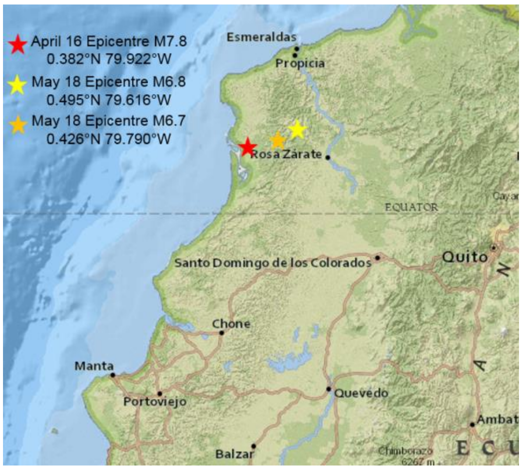

Figure 2. Epicentre of the April 16 2016 Ecuador earthquake and May 18 aftershocks

In response to the April 16 earthquake, the state of emergency was declared [10] in the six most affected provinces: Esmeraldas, Manabí, Guayas, Santa Elena, Los Ríos and Santo Domingo. The National Guard was mobilized to assist in rescue and relief efforts, approximately 10,000 military personnel and 3,500 police officers were deployed [11]. Hydroelectric dams and oil pipelines were shut down as a precautionary measure.

2. Impact of the event in Portoviejo and Manabí Province

Portoviejo, capital and commercial centre of the Province of Manabí, has a total of 223,086 inhabitants in the city and 280,029 in the metro area. The city covers an area of 954.9 km^2 and it is formed by 221 blocks in total, 52 of those are in the city centre where the main business and commercial sectors are located. Following the April 16 earthquake, the city centre was denominated as Zone Zero because it was the most affected area in Portoviejo, as illustrated in Figure 3. There were approximately 1,000 commercial establishments in Zone Zero that were closed after the earthquake, distressing the economy and the local community. 133 out of the 663 casualties from the earthquake took place in the city centre of Portoviejo.

Figure 3. Aerial view of Portoviejo Zone Zero. Photo taken following the April 16 earthquake.

It was observed that poorly built structures were a significant factor in casualties and overall damage. Within Portoviejo, reinforced concrete (RC) is the main construction material, while wood is used in older buildings and there are still several buildings which use traditional construction materials like bamboo and clay. Traditional construction types are made with wood and masonry walls (see Figure 4) or wood and “quincha” (bamboo covered with mud) walls (see Figure 5). While many of these buildings were not engineered, in general, they performed relatively well due to their light weight and flexibility. Damage observations in these buildings were attributed to poor maintenance.

(a) (b) (c)

Figure 4. Wood and masonry buildings.

(a) (b)

Figure 5. Wood and “quincha” buildings.

While modern building codes exist in Ecuador, Normas Ecuatorianas de Construccion [12], the observed damage suffered by many low and mid-rise RC buildings, such as those shown in Figure 6, suggests there was a lack of adequate seismic detailing and/or quality control which resulted in total or partial collapse of numerous buildings.

(a) (b)

Figure 6. Severely damaged RC buildings in Portoviejo (a) and Manta (b).

In many instances, RC buildings performed relatively well, but due to the presence of single layer unreinforced clay masonry used as infill walls, there was significant non-structural damage. In most instances, to save time and material costs, the walls were constructed by placing bricks laid on the long narrow side with the broad face of the brick exposed, leading to walls extremely susceptible to seismic damage. This type of wall was named “parado” (Figure 7).

(a) (b) (c)

Figure 7. Examples of the typical non-bearing slender masonry wall named “parado”.

When the infill walls were built outside the structural frame, small RC columns, named “columnitas”, were placed between floors in order to confine or anchor the infill walls (Figure 8a). In some cases the bearing RC columns, larger than the “columnitas”, could be clearly identified (Figure 8b). In other cases, the presence of RC columns remained questionable (Figure 8c), where a “columnita” continues at upper storeys in the same position where a column is placed at ground level.

(a) (b) (c)

Figure 8. Examples of “columnitas.”

In RC buildings, brittle shear failures prevailed among other types of structural damage (Figure 9). In some cases, brittle failure was triggered by pounding effects with adjacent buildings or adverse interaction of the RC frame with the infill walls (Figure 10). Less frequently, a more ductile behaviour was observed with plastic hinge development at the base of ground floor columns (Figure 11). Few cases of soft storey mechanism were reported in upper storeys (Figure 12).

(a) (b) (c)

Figure 9. Brittle shear failures in RC buildings.

(a) (b)

Figure 10. Brittle failures due to pounding (a) and interaction between RC frame and infill wall (b).

(a) (b) (c)

Figure 11. Plastic hinges at the base of RC columns.

(a) (b)

Figure 12. Soft storey mechanism at upper storeys.

Light metallic roofs are very common in the area (Figure 13a, b). From a seismic performance perspective, the low weight of these roofs is beneficial. However, the lack of rigid floor at top of the building results in inadequate protection from debris or other falling objects from adjacent buildings (Figure 13c).

(a) (b) (c)

Figure 13. Light roofs on top of terraces.

Damage to non-structural components was widespread due to the fact that they were not properly anchored to walls or roofs (Figure 14).

(a) (b) (c)

(d) (e) (f)

Figure 14. Damage to non-structural components and building contents.

The damage that has been observed and described is consistent with the damage reported by other international reconnaissance teams on the field [13, 14].

3. Structure of inspection management

The Ecuadorian emergency management organisation is composed by Emergency Operation Centres (Comité de Operaciones de Emergencia, COE) that operate at national, provincial and municipal level. Ecuador is divided into 24 provinces and each province has its own administrative capital. Provinces are divided into cantons and these subdivided into parishes. COE are inter-institutional bodies responsible within their territory to coordinate actions aimed at reducing risk as well as response and recovery in emergencies and disasters. They operate under the principle of subsidiary decentralization, which involves the direct responsibility of the institutions within its geographical area. The Secretaría Nacional Técnica de Gestión de Riesgos (SGR) regulates the establishment and the functioning of the centres.

COE operates in clusters, similar to the ones developed by the United Nations, Office for Coordination of Humanitarian Affairs [15]. Clusters are named "Mesas Técnicas de Trabajo" and are functioning at national, provincial and municipal level. The information goes through these levels within the same cluster. The Emergency Operations Centre of the Manabí province was located at the 911 building in Portoviejo.

To accommodate Portoviejo citizens whose primary residence was damaged, local authorities organized shelter at the old Airport Reales Tamarindos just a few hours after the earthquake. On April 17, the authorities performed an aerial inspection with drones around Zone Zero, with the purpose of getting an overall picture of the damage and to support the search and rescue teams. Electricity and water were cut off because of the earthquake. Within Zone Zero, the local authorities cut the cables that had fallen and provided support to rescue services. Outside of Zone Zero, locals reported that electricity was restored within 72 hours and water supply resumed within one week. On April 18, local authorities cordoned off the city centre, which was guarded by police forces to prevent locals from going into the area without authorization. Also on April 18, local authorities organized several routes to conduct structural assessments of the constructions located within the centre of Portoviejo and some nearby areas. The Ministry of Urban Development and Housing ("Ministerio de Desarrollo Urbano y Vivienda" or MIDUVI) was the institution responsible for the damage assessments of buildings and infrastructure. "Mesa" or cluster 3, Public Infrastructure, was the "Mesa Técnica de Trabajo" responsible for damage assessments.

Building inspections started on April 19, with a total of 18 groups working simultaneously in different areas. Groups were formed by volunteers from the Technical University of Manabí, San Gregorio University, Escuela Superior Politécnica del Litoral (ESPOL) and the Spanish TRAGSA Group (private company). Each group had at least one structural engineer and one representative from the cadastral services. The authorities provided the teams with a map of the area to be inspected. Inspections were only external and extremely rapid. They were aimed at obtaining a general overview of the situation. On April 20, consultants from AOC Ingeniería and experts from Ecuador's Catholic University joined the working groups. Table 1 provides a summary of the structural assessments conducted between April 19 and 24. Inspection results were managed through Geographical Information System (GIS).

Table 1. Structural assessments in Portoviejo before arrival of EU teams

	Collapsed	**Possible collapsed (Red tagged)**	**Partial damage (Yellow tagged)**	**Not Affected (Green tagged)**	**Total**
No. of buildings	120	334	531	250	1235

It is worth noting that Portoviejo had implemented its own methodology and procedure for post-earthquake safety assessment. The assessment form and the tagging system, later described, were derived from ATC 20 documents [16, 17] with minor modifications in order to target common building construction practices and building typologies in the area. In municipalities other than Portoviejo, such as Manta and Pedernales, the situation was quite different. The damage assessment was not managed with GIS and no formal procedures were in place to conduct post-earthquake assessments, perhaps because local authorities were less proactive than in Portoviejo.

To face the emergency, on April 17, Ecuador made a request for international assistance. Within the framework of the European Union Civil Protection Mechanism (EUCPM) [18], a European Union Civil Protection Team (EUCPT) deployed to Ecuador. The team was composed by ten experts, seven experienced in emergency coordination and three structural engineers. The mission mandate was to facilitate the coordination of incoming assistance from Participating States (28 EU Member States in addition to Iceland, Montenegro, Norway, Serbia, the former Yugoslav Republic of Macedonia and Turkey) and to support the Ecuadorian authorities in assessing the situation and notably on structural damage. The team arrived in Quito at different times from April 20 to 22. Six experts, including the structural engineers, deployed to Portoviejo, the others remained in Quito to liaise with national authorities. In addition to the EUCPT, Italy (IT) and France (FR) also deployed teams of experts under the EUCPM, while the United Kingdom (UK) deployed a separate team of experts through a bilateral agreement with the Ecuadorian government, as follows:

- The IT team was composed by eight firefighters from the Italian Fire and Rescue Service, one team leader (TL) and 1 liaison officer (LO) from the Italian Civil Protection Department. They operated in Portoviejo with 3 sub-teams from April 25 to May 4. One day they operated in Manta.
- The FR team was composed by six firefighters coming from French Securitè Civile. They operated in Portoviejo with two sub-teams from April 26 to May 7. One day they operated in Calderon, a rural parish in the municipality of Portoviejo.
- The UK team was composed of three structural experts who operated as one team from April 27 to May 5 in Pedernales, a smaller city also within the Province of Manabí.

Upon arrival in Portoviejo on April 24, the EUCPT and members of the IT team held a meeting at the On Site Operations and Coordination Centre (OSOCC) [19] with United Nation Disaster Assessment and Coordination (UNDAC) team [19] and representatives from SGR and MIDUVI (see Figure 15a). MIDUVI defined Portoviejo as Site of Operations (SoO) for all EU structural assessment teams. After discussions with the municipality of Portoviejo, the structural assessment efforts were focused in the city centre.

(a) (b)

Figure 15. Coordination meeting at OSOCC with EUCPT, IT team, UNDAC, SGR and MIDUVI to define SoO (a) and first meeting of the EUCPT at Colegio de Ingenieros (b).

The municipality of Portoviejo requested that the European teams re-assess all buildings that had been rapidly inspected prior to their arrival using a more rigorous approach. The new assessment was managed by the Cadastral Unit of the Public Services Department of the Gobierno Autonomo Decentralizado (GAD) of Portoviejo Canton, at the Colegio de Ingenieros (see Figure 15b), close to the old airport, where the following activities were performed:

- Team composition: teams were composed of 2 to 3 international experts and 1 to 2 national experts. Usually the same local experts were associated to the international team. The field of expertise was engineering and architecture;
- Task assignment based on priorities defined by the local authority;
- Daily reporting from assessment teams to local authorities;
- Data computerisation in GIS;
- Data reporting to EUCPT;
- Data reporting to “Mesa” or cluster 3, COE provincial Manabí.

Forms completed on the field have been associated to the polygons of the Municipal GIS through a unique ID. Tasks were assigned through paper cadastral maps where buildings to be inspected were highlighted and their ID was shown. Hence building addresses were not needed and even when street numbers were missing, the inspection process was not compromised. Similarly taking GPS coordinates on the field was not necessary. When inspectors identified additional buildings on the field, they were allowed to define new IDs. Outside Portoviejo Zone Zero inspections were performed upon direct requests made by citizens at a special desk at Colegio de Ingenieros. EU teams were generally not involved in such assessments. After the two strong aftershocks that occurred on May 18, COE was re-activated at all levels (national, provinces and cantons) and MIDUVI began to reassess buildings for further damage.

4. Field structural assessments

In Portoviejo, EUCPT and IT and FR teams operated in the Zone Zero, delimited by the red dashed lines in Figure 16, and specifically in the blocks shown in green and orange and along main roads shown in red in the same figure.

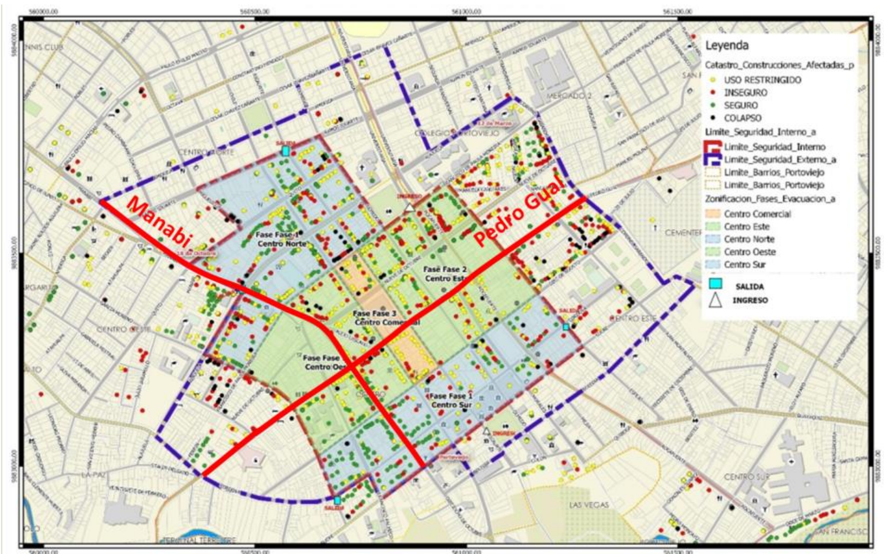

Figure 16. Map of the city centre of Portoviejo, which illustrates the extents of the cordoned off area, referred to as Zone Zero (delimited by the red dashed lines). Red continuous lines show the two main roads assessed for safe access.

The IT and FR teams and, when possible, the EUCPT team conducted several types of assessment, based on needs and priorities established by Ecuadorian authorities. Teams of engineers conducting building evaluations were always composed of EU international experts accompanied by local engineers and other volunteers both to facilitate entrance into buildings, knowledge transfer and to have the authority of tagging buildings. Informal training was conducted during the building assessments to ensure the skills were retained by the local community after the end of the mission. The following field assessments were performed:

- Rapid post-earthquake building assessment on 510 buildings in Portoviejo and 144 in Pedernales;
- Demolition confirmation on 192 buildings in Portoviejo;
- Evaluation of safe access routes which required assessment of 153 buildings in Portoviejo;
- Detailed post-earthquake building assessment on 159 buildings in Portoviejo.

The order reflects the priorities defined by the municipality of Portoviejo.

a. Rapid Post-Earthquake Building Assessment

Rapid post-earthquake building assessments were performed on all the buildings located in Portoviejo Zone Zero. The methodology and the procedures were already in place when the teams arrived there. They were mainly based on ATC 20 documentation [16, 17] arranged to fit local building types. Buildings were tagged as Green, Yellow or Red, as shown in Figure 17, following a quick, but thorough evaluation of the risk that damaged building may impose on occupants and surrounding areas. As outlined in ATC 20 [16, 17], the implications of each tag are as follows:

- Green: A Green tag indicates that no damage observed during the inspection poses a safety risk for entry or occupancy of the building.
- Yellow: A yellow placard indicates that there are restrictions on the building usage. The restrictions are based on the inspection team's judgment. A yellow tag might allow occupants to enter for a short time to remove contents but the building is not safe for longer occupancy.
- Red: A red placard indicates that the building is unsafe for occupancy. However, it does not mean that the building must be demolished. In certain occasions, a building may be tagged as red due to non-structural damage only or due to hazards from surrounding buildings.

Figure 17. The tagging system implemented in Portoviejo

Structural damage caused buildings to be tagged as red. Frequently, non-structural damage caused buildings to be tagged as yellow, i.e. restricted access, due to the hazard posed by falling debris. This was particularly important when damage occurred in the masonry infill walls of multi-story buildings, which also required cordoning off areas of the sidewalk to avoid injury from falling debris.

Six teams (3 IT, 2 FR and 1 EUCP) operated on the 52 blocks located in Zone Zero. All the buildings in the same block were inspected by the same team. The average number of buildings per block was 30 and the average number of inspected buildings per day per team was 25. This type of assessment was conducted from April 25 to April 30 with an average number of inspections per day equal to 85. The summary of the daily activity is shown in Table 2. Figure 18 illustrates members of the EUCPT conducting surveys with local engineers.

Table 2. Rapid inspections in Portoviejo

	Green	**Yellow**	**Red**	Total
Building Count	172	180	158	510
Percentage (%)	34	35	31	100

(a) (b) (c)

Figure 18. Carlos (a), Agostino (b) and Lida (c) assessing buildings in Portoviejo Zone Zero with national experts

Table 3 reports the assessments performed by national experts before arrival of the EU teams. The increase in the percentage of buildings that are green-tagged following inspections by EU teams, were beneficial to the recovery of Zone Zero and preventing overestimating the damage in the area. During inspections, security in Zone Zero was not an issue since the whole area was cordoned-off and guarded by the police, as shown in Figure 19. The form that has been used for the rapid assessment is included in the appendix at the end of the paper.

Table 3. Percentages of buildings tagged by national and international experts with rapid assessment

	Green	Yellow	Red
Before arrival of EU teams	22%	48%	30%
EU team assessments	34%	35%	31%

(a) (b)

Figure 19. Cordon in Portoviejo Zone Zero (a), and national experts embedded in the EUCPT tagging a building (b).

In Pedernales, the same assessment procedure was not initially in place. However, the EUCPT suggested to the UK team to use the same inspection form and tagging system with an average of 16 inspections per day. The summary of assessments in Pedernales is shown in Table 4. Considering that in Pedernales there was just one team, this value is consistent with the one observed in Portoviejo.

Table 4. Rapid inspections in Pedernales

	Green	Yellow	Red	Total
Building Count	56	40	48	144
Percentage (%)	39	28	33	100

b. Demolition Verification

A large number of buildings had already been selected for demolition, particularly in the Zone Zero of Portoviejo, when the EUCPT arrived. Demolitions were often performed with inadequate vehicles and with limited concern for public safety (Figure 20a), which often resulted in the sudden collapse of the building (Figure 20b). Demolition work was initiated so soon after the earthquake due to the immediate availability of vehicles (up to 80) and demolition equipment provided by Ministry of Transport and Public Works. As a result, many buildings were demolished in the absence of a structured procedure. Citizens feared their houses would be demolished without their approval or removal of their goods. These concerns resulted in signs posted on buildings by owners, as seen in Figure 21, prohibiting demolition.

(a)

(b)

Figure 20. Demolition of a 3-storey building outside Zone Zero (a), and building collapse in Zone Zero during demolition (b).

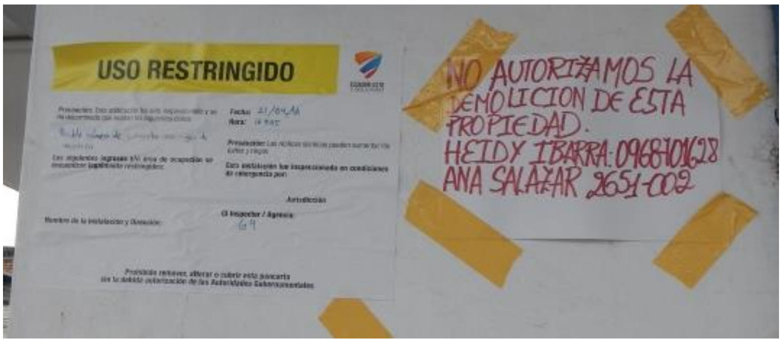

Figure 21. Yellow tagged building and owner statement in response: “We do not authorize the demolition of this property.”

As a result of these concerns, the municipality of Portoviejo requested that the EUCPT conduct additional assessments of all red tagged buildings inside and outside Portoviejo Zone Zero prior to proceeding with demolition work in order to ensure that none of the buildings that could be repaired were demolished. For this purpose, a specific form was drafted by the EUCPT experts to summarize the results of the assessment. In total 153 buildings were assessed for demolition verification in Portoviejo from April 28 to April 30 and about 8% required demolition The placard shown in Figure 22a was used to identify red tagged buildings that required demolition as seen in Figure 22b and c.

(a)

(b) (c)

Figure 22. Placard for demolition, associated only with red tagged buildings (a) and two cases of buildings tagged for demolition (b), (c).

c. Safe Road Access through Zone Zero

The city centre of Portoviejo was an area devoted to commercial activities. Its closure due to widespread damage following the April 2016 earthquake had an important economic and symbolic impact on the population. As a result, the municipality of Portoviejo wanted to re-establish access to the area. To this end, ensuring safe access roads through Zone Zero was set as an additional priority and task for the EUCPT. In order to re-establish circulation through the area, the two main arteries of Zone Zero, Manabi and Pedro Gual, as illustrated Figure 16, were selected for safe-road access assessment. Since no established methodology was available, a form was drafted by EUCPT experts. The form outlined any elements to be removed or propped, or the fencing to be set up, on buildings alongside the road in order to enable safe access. The form is included in the Appendix at the end of this paper. All buildings alongside Manabi and Pedro Gual were assessed for safe route access in Portoviejo Zone Zero on May 1 and May 2. Immediate interventions were prescribed for 192 buildings.

(a) (b) (c)

Figure 23. Cleared roads in Portoviejo Zone Zero (a) and (b), bamboo propping (c)

(a) (b) (c)

Figure 24. Examples of buildings with high risk of unstable elements falling on the street

In order to enable safe road access, the streets had to be cleared from the debris from partially or totally collapsed buildings as seen in Figure 23a and 23b. In few instances, temporary shoring was required to stabilize damaged buildings, as shown in Figure 23c. Additionally, objects hanging from damaged buildings over the streets, as seen in Figure 24, had to be removed or stabilized. Lastly, some buildings had to be demolished due to the high risk of collapse.

d. Detailed Post-Earthquake Safety Assessment of Buildings

Detailed post-earthquake assessments were performed after rapid safety evaluations were complete. The same tagging procedure as that noted in the rapid assessment was adopted (Red, Yellow and Green placards). However, the assessment entailed a more thorough review of the building. To ensure greater detail, a form was drafted by EUCPT structural experts, based on ATC 20 [16, 17] documentation that was adjusted to the local context. The experience gained during the rapid assessments, was beneficial to the development of the form, which provided additional information relating to the damage grade and the damage extent to all building components.

Detailed post-earthquake safety evaluations were conducted for critical buildings, such as hospitals, schools, public buildings, etc. under the direct request of Ecuadorian authorities, who prepared a daily list of buildings to be inspected, with their corresponding location and their building IDs. The EU teams operated in Portoviejo with the exception of the FR team, which deployed to Calderon, a rural parish outside Portoviejo and the IT team, which deployed to Manta to assess a Hospital and a Church. In total 159 buildings were evaluated following the detailed assessment procedure from May 1 to May 7. The results are reported in Table 5.

Table 5. Summary of detailed post-earthquake safety inspections

	Green	**Yellow**	**Red**	Total
Building Count	92	26	41	159
Percentage (%)	58	16	26	100

On average, about 13 detailed assessments were performed per day per team. Because detailed assessment were performed on selected buildings typically located outside the most damaged area (Zone Zero), where the rapid assessment took place, the percentage of green tagged buildings is greater for the detailed evaluations (58%) than for the rapid assessments (34%). Detailed assessments have a significantly lower number of yellow-tagged buildings, yet surprisingly, the percentage of red-tagged buildings (26%) was roughly consistent with the rapid assessments (31%). The form developed for the detailed assessments is included in the appendix at the end of the paper.

5. Investment in DRR project

At the time of the April 16 earthquake, an investment project aimed to contribute to seismic DRR in Ecuador, at national, local and community level was underway. The project was funded by the European Commission Humanitarian Aid & Civil Protection (DG-ECHO) with its implementation being led by the United Nations Development Programme (UNDP) in partnership with the SGR and MIDUVI.

The aim of the project was to support national and local governments in disaster seismic risk reduction, by the implementation of guidelines, training activities and pilot projects in communities, in order to reduce population risk through achieving safer building structures. The project drew on the new Ecuadorian Construction Code or Normas Ecuatorianas de Construccion (NEC) regulations [12] and consisted of four key objectives:

A. To develop practical design, construction and seismic building evaluation tools to improve capacities at national and local level, in public and private sectors;
B. To train national and local government officials, university professors, continuing education instructors, students and construction workers to build safer buildings under NEC regulations;
C. To develop seismic risk management plans for neighbourhoods and communities and implement measures to mitigate building vulnerabilities in communities;
D. To help officials and communities to learn from experiences of other south-American countries in DRR providing procedures for construction quality control and seismic evaluation of buildings.

The pilot project was only to be implemented in two cantons, Ibarra and Duran, which developed mechanisms for NEC regulations compliance verification in design and construction phases (for new building structures) and in seismic evaluation of existing buildings (pre and post event). Ibarra is located 70 km north-east of Quito. Duran is immediately east of Guayaquil. These locations were not severely affected by the April 16 earthquake, with only light-to-moderate perceived shaking and none-to-very light potential damage [20]. As a result, it was not possible to measure the impact of the pilot study in reducing seismic vulnerability for this particular earthquake event. Nevertheless, because of the SGR's and MIDUVI's involvement in the pilot DRR project, as well as in their involvement in the response following the April 16 earthquake, knowledge transfer enabled the implementation of these initiatives in Portoviejo, particularly those related to the protocols for the seismic evaluation of buildings in post seismic event stages, which MIDUVI and SGR had to validate for implementation in Ibarra and Duran as part of the pilot study.

The most tangible sign of the DRR project in the earthquake response activity was the use of building tags in the post-earthquake safety evaluation of buildings, as shown in Figure 17. The overall project was completed following the April 2016 earthquake [21]. Observations from the devastating earthquake were included in the final outputs of the project, particularly those related to the post-earthquake safety evaluation of buildings [22]. While the DRR project had not been fully implemented at the time of the devastating earthquake, such investment in DRR benefitted the disaster response efforts even in areas which were not directly involved in the pilot program.

6. Lessons identified

Several lessons were identified during this mission, which can benefit future deployments as well as seismic DRR investments. They are summarized in the following points:

- Self-sufficiency is an important issue in the efficiency and operational capabilities of deployed teams. Lack of self-sufficiency from any team can hinder response and recovery efforts.
- The lack of a coordination tent, power and fast internet access can severely impact the efficiency of response teams. It took several days for the EUCPT to have generators and a coordination tent, both eventually provided by the UNDAC team. About 50% of the EUCPT in Portoviejo was not self-sufficient. This required significant time to prepare the deployment from Quito to Portoviejo.
- Coordination of the technical activities is vital to fully exploit the team's operational capabilities. To facilitate EU team task assignments in terms of structural assessments, one EUCPT structural expert was permanently deployed to the centre for coordination of the structural assessments at the Colegio de Ingenieros, where meetings with other teams and local authorities took place. The material needed for task assignments was prepared in advance in order to maximize productivity. Data management to monitor both the performed inspections and the inspections still to be performed was essential.
- In terms of operations, teams need to be flexible enough to perform different types of activities according to the local needs, including (i) rapid post-earthquake safety evaluations of buildings, (ii) demolition verification, (iii) safe road access and (iv) detailed post-earthquake safety assessment of critical buildings. Local engineers should be embedded in the international teams both to facilitate entrance into buildings, knowledge transfer and to have the authority of tagging buildings. When

possible all on site capacities should fit into the same procedure and methodology. Appropriate building identification and link to GIS should be considered in advance.

- Developing a positive relationship with affected citizens is essential. Inspections were often repeated because owners were not able to grant immediate access to buildings. Interacting with citizens who are retrieving their goods from buildings in Zone Zero or occupying red tagged buildings can be intricate and have security implications. The presence of national experts in all assessments can ease tensions and help ensure the development of a positive collaboration.
- To avoid language and transportation barriers, the inspection forms were drafted in Spanish as few local experts were able to speak English. Fluency in the local language is preferable. Other solutions include the use of interpreters or translation of the form into several languages prior to inspections, yet this can impact productivity. As for transportation, several cars were needed every day to reach the SoO. This was particularly important when performing inspections on request (detailed assessments) rather than on a building-by-building basis (rapid assessments). Transportation for local engineers should be considered as well, as these may not have access to vehicles.

7. Conclusions

Despite the small number of structural experts (8 IT, 6 FR, 3 EUCPT) more than 1,000 buildings were inspected in Portoviejo and about 150 in Pedernales. The high number of inspected buildings is a proof of the team's capabilities. The most impactful result of the EUCPT mission was to obtain a more precise and homogenous safety evaluation of damaged buildings, increasing the number of usable buildings (Green tagged), reducing the number buildings with restricted use (Yellow tagged), as well as reducing the number of buildings requiring demolition.

The EUCPT was able to facilitate the coordination of the EU capacities and liaise with Ecuadorian authorities. More specifically EUCPT was flexible enough to i) facilitate the activities of other teams (IT, FR and UK), ii) support local authorities in planning and drafting proper methodologies and tools, iii) perform direct assessments and iv) support OSOCC activities. The methodologies and tools developed are included in the appendix at the end of this paper to aid post-earthquake safety evaluations in Spanish speaking countries in future missions. The forms were used during the EUCPT mission to Ecuador with no evidence of shortcomings or deficiencies. However, to validate their design, these forms must be used in different contexts and feedback from different inspection management teams would need to be collected to identify items that can be improved to facilitate their widespread use.

The efforts of EUCPT largely benefitted from a DRR pilot project which was underway at the time of the earthquake. While the project was not yet complete, such investment in DRR benefitted the disaster response efforts, even in areas which were not directly involved in the program.

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FORMULARIO DE EVALUACIÓN RÁPIDA

Inspección:

CI Inspector: ______________________________ Hora y lugar de la inspección: ______________ o AM o PM

Afiliación:________________________________ Áreas inspeccionadas: o Solo exterior o Exterior e Interior

Descripción de la edificación:

Nombre de la edificación: _____________________

Dirección: __________________________________

____

Número de contacto celular de la edificación: _____

Número de pisos sobre el suelo: ___Subsuelos:____

Área en planta (m^2 o ft^2):______________________

Número de residencias habitadas: ______________

Número de residencias no habitadas : ___________

Tipo de Construcción

o Estructura de madera

o Estructura metálica

o Estructura modular prefabricada

o Estructura de hormigón

o Estructura con muros de hormigón

o Mampostería sin refuerzo estructural

o Mampostería sin refuerzo estructural

o Otros: _______________

Tipo de Ocupación

o Familiar

o Otro tipo de residencia

o Asamblea pública

o Servicios de emergencia

o Comercio o Gubernamental

o Oficinas o Histórica

o Industrial o Colegio

o Otros: _______________

Evaluación:

Investigar la edificación y marcar sus condiciones en una de las columnas:

Condiciones observadas:	Poca/ Ninguna	Moderada	Severa
Colapso total, parcial o su cimentación afectada	o	o	o
Edificación fuera de plomo	o	o	o
Apretamiento en muros u otro daño estructural	o	o	o
Daños en el antepecho, chimenea u otra elemento che amenace con caer	o	o	o
Otro (especificar)	o	o	o
Condiciones observadas: ______________________________ ____	o	o	o

Estimación de daños
(Excluyendo contenidos)

o Ninguno

o 0-1%

o 1-10%

o 10-30%

o 30-60%

o 60-100%

o 100%

Comentarios:

____

Marcación:

Determinar la marcación de la estructura en base a la evaluación y al juicio del equipo de investigación. Las condicionas severas que amenacen el estado estructural de la edificación son suficientes para clasificarla como INSEGURA. Condiciones de daños severas y moderadas pueden clasificar a la estructura como USO RESTRINGIDO. Marcar a las estructuras con la pancarta INSPECCIONADA únicamente en la entrada principal. Marcar a las estructuras con la pancarta de USO RESTRINGIDO e INSEGURA en todas las entradas.

o INSPECCIONADA (Pancarta Verde) o USO RESTRINGIDO (Pancarta Amarilla) o INSEGURA (Pancarta Roja)

Identificar cualquier restricción de uso existente al igual que en la pancarta de marcación:

____

____

Futuras acciones:

Indicar en cualquiera de las cajas que se enseñan a continuación en caso de que se necesitan futuras acciones

Investigar la edificación y marcar sus condiciones en una de las columnas

o Uso de barricadas en las siguientes áreas ____

____

o Recomendación de Evaluación Detallada o Estructural o Geotecnia o Otra:

____

o Otra recomendación: ____

Comentarios: ____

____

FICHA PARA GARANTIZAR EL ACCESO SEGURO A LA VÍA PÚBLICA

INSPECCIÓN

Nombre y Apellido ____	Día ________________	Hora ________________

IDENTIFICACIÓN DE LA EDIFICACIÓN

Clave Predial ________________ Código Único ________________ Vía afectada ________________

VALLADO (CERCADO) DE SEGURIDAD

Que distancia (en metros) debe ser vallada desde el límite del predio al centro de la vía para asegurar un tránsito seguro por la vía pública?

RETIRADA DE ELEMENTOS PELIGROSOS

Que elementos (estructurales o no estructurales) deben ser retirados para permitir que se quite el vallado de seguridad? Especificar elemento, ubicación cantidad a retirar.

	Ubicación	Cantidad	Observaciones
☐ Cubierta metálica			
☐ Mampostería			
☐ Revestimiento fachada o techo			
☐ Ventanas			
☐ Balcones			
☐ Letreros			
☐ Instalaciones			
☐ Escombros			
☐ Otros: ________________			

APUNTALAMIENTO

Indique si tras la retirada de los elementos peligrosos y el vallado de seguridad se necesita apuntalamiento de la fachada o edificio para garantizar el paso seguro por la vía pública.

ALZADO (VISTA DE FRENTE)

Nivel de la calle

PLANTA

LINEA CENTRAL VIA PUBLICA

Límite *del Predio*

COMENTARIOS

FORMULARIO DE EVALUACIÓN DETALLADA

INSPECCIÓN

NOMBRE Y APELLIDO: ____________________ DÍA: ____________ HORA: ____________

IDENTIFICACIÓN DE LA EDIFICACIÓN

CLAVE PREDIAL ____________ CÓDIGO ÚNICO ____________ AREAS INSPECCIONADAS: ☐ Solo Exterior ☐ Exterior e Interior

DESCRIPCIÓN DE LA EDIFICACIÓN

Nombre de la edificación: ____________________

____

Dirección: ____________________

Número de contacto: ____________________

Número de pisos sobre el suelo: ____________________

Número de subsuelos: ____________________

Área en planta (m^2): ____________________

Número de residencias: ____________________

Tipo de Construcción

- ☐ Madera y Quincha (caña revertida con barro)
- ☐ Mampostería y madera (construcción mixta)
- ☐ Mampostería y hormigón (construcción mixta)
- ☐ Estructura de madera
- ☐ Estructura de hormigón
- ☐ Estructura metálica
- ☐ Mampostería sin refuerzo estructural
- ☐ Mampostería con refuerzo estructural
- ☐ Otros: ____________

Tipo de Ocupación

- ☐ Residencial
- ☐ Comercial
- ☐ Oficinas
- ☐ Industrial
- ☐ Escolar
- ☐ Hospital
- ☐ Edificio de gobierno
- ☐ Otros: ____________

____

Tipo de Techo: ☐ Flexible ☐ Rígido

Tipo de Piso: ☐ Flexible ☐ Rígido

ESTIMACIÓN DE PÉRDIDAS ECONÓMICAS Y DE DAÑOS DE LA EDIFICACIÓN

Estime el daño de la edificación expresado como el coste de reparar sobre el coste total (sin tener en cuenta los contenidos):

☐ Sin daños ☐ 0-1% ☐ 2-10% ☐ 11-30% ☐ 31-60% ☐ 61-99% ☐ 100%

Grado de daños donde cero representa sin daños y cinco representa daño total: ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

DIAGRAMA Y COMENTATIOS

Produzca un diagrama de la edificación, de las porciones dañadas o de daños particulares observados:

EVALUACIÓN

Investigue las siguientes condiciones de la edificación e indique la clasificación correspondiente:

	Ninguno	Poco			Moderado			Severo		
		<1/3	1/3<e<2/3	>2/3	<1/3	1/3<e<2/3	>2/3	<1/3	1/3<e<2/3	>2/3
Riesgos generales:										
Colapso (total o parcial)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Edificio fuera de plomo	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Otros: ______________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Riesgos estructurales:										
Cimentaciones	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Techo	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Losas	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Vigas	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Columnas	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Muros	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Contravientos	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Conexiones / Uniones	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Otros: ______________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Riesgos no estructurales:										
Antepechos	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fachada	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mampostería interna	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mampostería externa	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Gypsum (techo o pared)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Escaleras	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Letreros	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Escombros	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Otros: ______________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Riesgos de suelos:										
Movimiento diferencial	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fisuras	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Otros: ______________	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Riesgos externo										
Cada de elementos de edificios adyacentes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

MARCACION

Si existe marcación previa (posiblemente de la evaluación rápida), indíquela aquí: ☐ INSPECCIONADA ☐ USO RESTRINGIDO ☐ INSEGURO

Determinar la marcación de la estructura en base a la evaluación y al juicio del equipo de investigación. Las condiciones severas que amenacen el estado de la estructura de una edificación son suficientes para clasificarla como insegura. Condiciones de daños severas y moderadas pueden clasificar a la estructura como uso restringido. Marcar a las estructuras con una pancarta inspeccionada únicamente en la entrada principal. Marcar la estructura con una pancarta de uso restringido e inseguro en todas las entradas.

☐ INSPECCIONADA (Pancarta Verde) ☐ USO RESTRINGIDO (Pancarta Amarilla) ☐ INSEGURO (Pancarta Roja)

Identificar cualquier restricción de uso existente al igual que en la pancarta de marcación:

____

____

____

RECOMENDACIONES

☐ REPARAR ☐ REFORZAR ☐ DEMOLICION PARCIAL ☐ DEMOLICION TOTAL

Reparar implica devolver la edificación a su estado anterior al sismo. Reforzar implica mejorar el diseño de la edificación con respecto a su estado anterior al sismo. Si se recomienda demolición parcial indique la porción a demoler ____________

FUTURAS ACCIONES

☐ VALLADO DE SEGURIDAD Especifique posición y dimensiones ____

☐ APUNTALAMIENTO Especifique elementos a apuntalar ____

☐ ELEMETOS A REMOVER Especifique elementos a apuntalar ____

Se recomienda una evaluación profesional detallada: ☐ ESTRUCTURAL ☐ GEOTECNICA ☐ OTROS: ____________________________