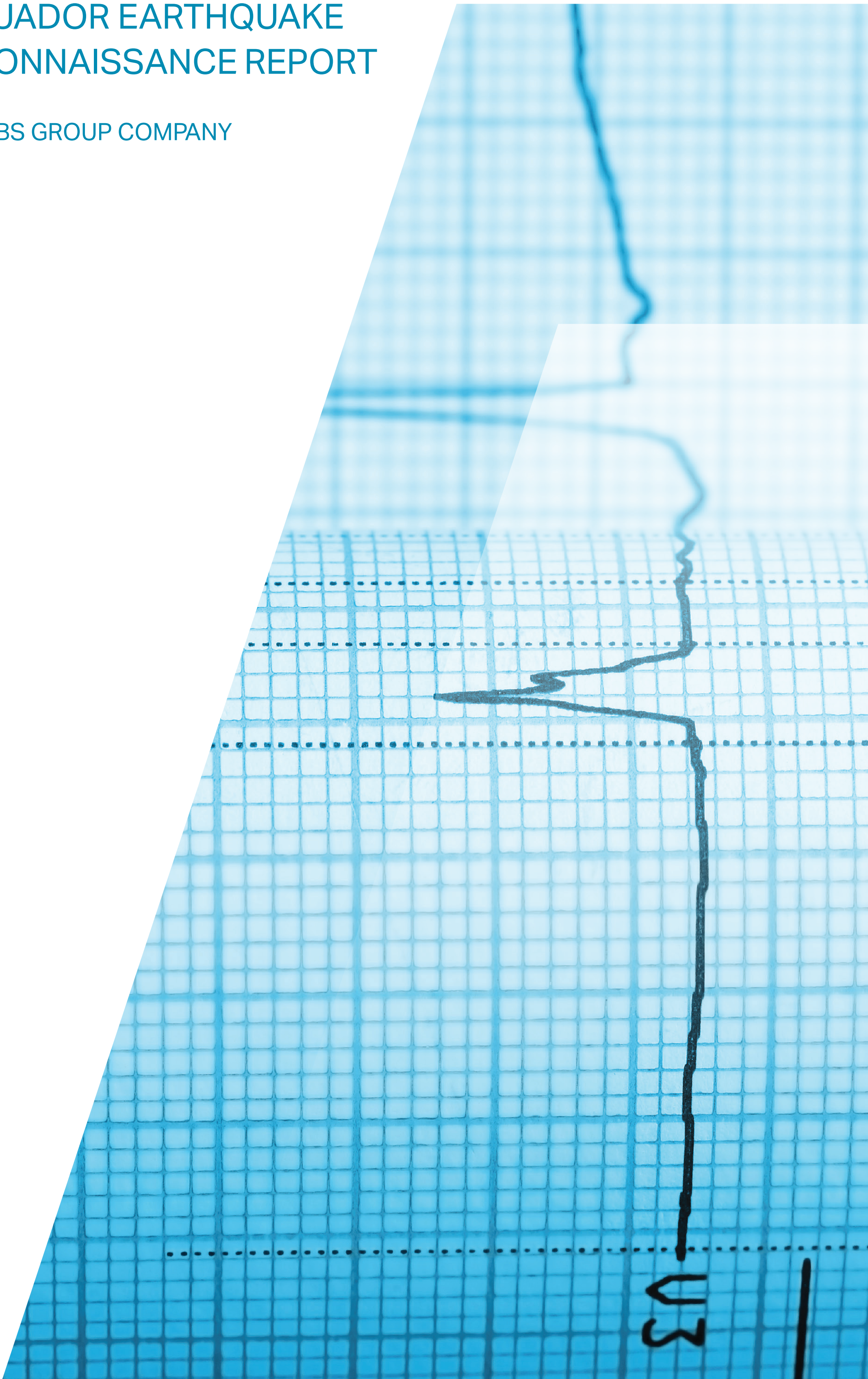
ABS Group

M7.8 COASTAL ECUADOR EARTHQUAKE PRELIMINARY RECONNAISSANCE REPORT

By ABS CONSULTING, AN ABS GROUP COMPANY
MAY 31, 2016



M7.8 Coastal Ecuador Earthquake

Preliminary ABS Consulting Reconnaissance Report

May 31, 2016

Summary

On Saturday April 16, 2016 at 18:58 local time, a magnitude M7.8 earthquake occurred in the oceanic plate subduction area between the Nazca Plate and the Northern Andean Block portion of the South American Plate. The epicenter was located in Coastal Northern Ecuador near the city of Muisne (0.37° N and 79.34° W), at a depth of 19 kilometers. The faulting was located on the Pacific "ring of fire" where the earth's tectonic oceanic plate subduction zones and related volcanic activity is common. Most of the observed damage, due to fault slip and associated ground shaking, was located to the south of the epicenter along the coast extending towards the City of Manta.

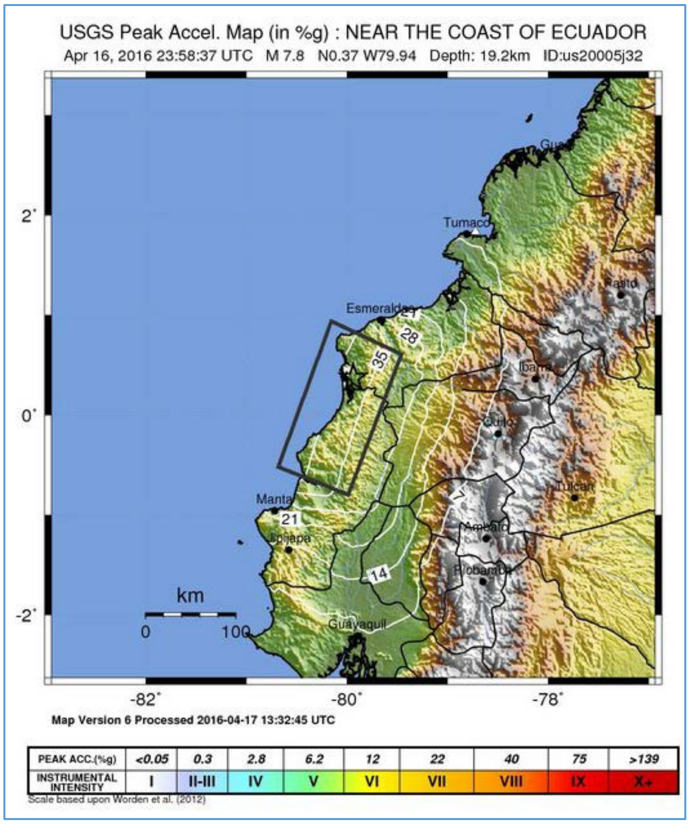
The earthquake ground shaking had devastating consequences, especially in the large coastal provinces of Esmeraldas and Manabi. Cities like Pedernales (spa and resort town), Portoviejo and the port of Manta in the province of Manabi, as well as Muisne in the province of Esmeraldas were especially hard hit by the earthquake. The earthquake heavily damaged buildings in urban areas and rural areas. The number of causalities due to the earthquake was approximately 660 people.

Three weeks following the earthquake, ABS Consulting sent a reconnaissance team consisting of three engineers from our Peru and California offices to survey the damage (Todd Erickson, S.E; Juan Chavez, PhD, P.E. and Engineer Carlos Barrera). The team surveyed the cities of Guayaquil, Portoviejo, Manta, Pedernales, Muisne, Atacames/Tonsupa and Esmeraldas from May 8 to May 15, 2016.

***This Preliminary Report** summarizes our observations and presents "lessons learned" from the earthquake. The damage was mainly observed in multi-story, single-family residential homes, as well as in mid- and low-rise buildings. The earthquake effects were amplified by the vulnerability of the observed non-ductile concrete construction (small resistant column sections, non-seismic detailing, building structural irregularities), effects due to stiff brick infill, interaction with directly adjacent structures, hillside construction effects, poor concrete materials and construction, perceived lack of engineering control and inspection during construction, and weak/soft soil conditions in some localized areas. Newer buildings exhibited far less damage than the older buildings, but in some cases newly constructed buildings exhibited similar levels of significant damage and even partial or total collapses.*

Coastal Ecuador Earthquake
Summary of Measured Seismicity (Ref. USGS)

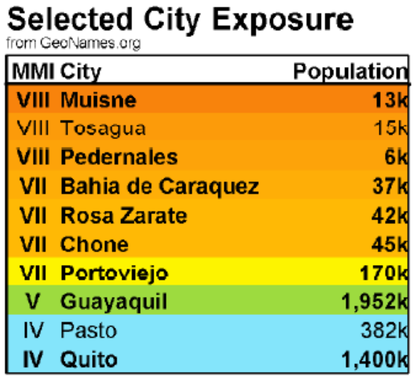
Date/time:	April 16, 2016 18:58 local (CDST)
Magnitude:	M7.8 (most recent large aftershock M6.7 May 16, 2016)
Epicenter:	Coastal Northern Ecuador, near the City of Muisne, 0.37° N, 79.94° W, depth 19 kilometers
Character:	Shallow coastal oceanic plate subduction between the Nazca Plate (Pacific Ocean) and the South American Plate (Northern Andean Block, NAB)
Shaking Intensity:	up to MMI VII-VIII (0.22 to 0.4g) over a large area
Death toll:	660 approx. (unverified)
Damage Cost:	< 1% GDP of Ecuador (estimated). With a few exceptions, most of the affected areas were in areas with commercial fishing, agricultural, or tourism



City Exposure & Intensity, Faulting Mechanisms

Summary of Approximate Peak Ground Acceleration (PGA) by Coastal City (Ref: USGS) from North to South. Asterisk (*) indicates cities visited by ABS Consulting's reconnaissance team:

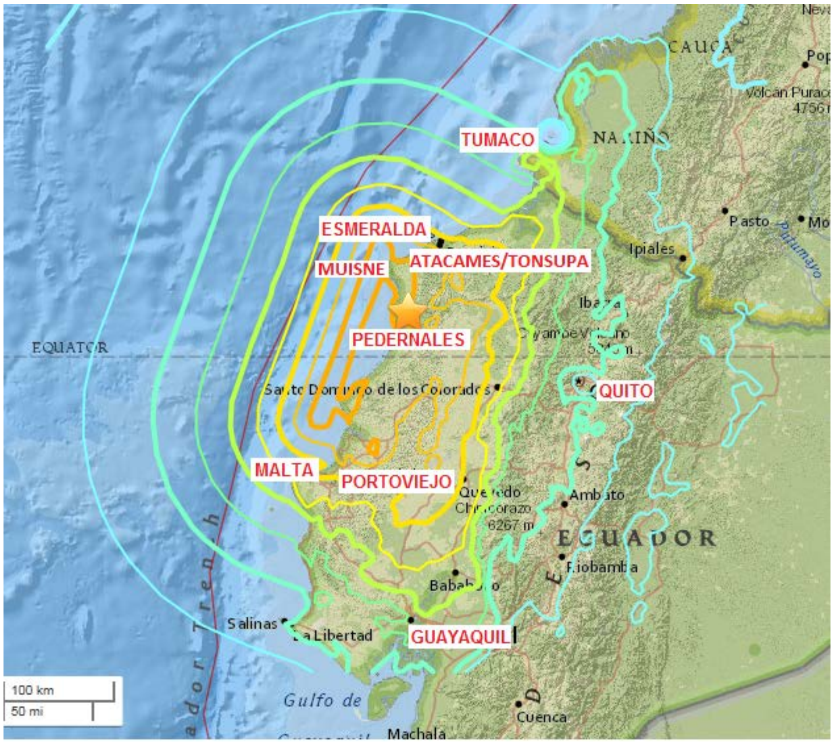
CITY	PGA	MMI	DIST TO EPICENTER	OBSERVED DAMAGE
*Esmeraldas	0.28g	VI	72km (NNE)	Negligible, few buildings
*Atacames/Tonsupa	0.35g	VII	58km (NNE)	None (surprisingly)
*Muisne	0.40g	VIII	28 km (north)	Some, significant to minor structures
Cojimies	0.40g	VIII	12km (west)	-
*Pedernales	0.37g	VIII	36km (south)	Widespread, devastating
*Quito	0.04g	IV	172km (east)	None
*Manta/Portoviejo	0.21g	VII	172km (SSW)	Significant, locally devastating
*Guayaquil	0.07g	V	280km (south)	Some, significant near airport



Selected City Exposure

from GeoNames.org

MMI	City	Population
VIII	Muisne	13k
VIII	Tosagua	15k
VIII	Pedernales	6k
VII	Bahia de Caraquez	37k
VII	Rosa Zarate	42k
VII	Chone	45k
VII	Portoviejo	170k
V	Guayaquil	1,952k
IV	Pasto	382k
IV	Quito	1,400k



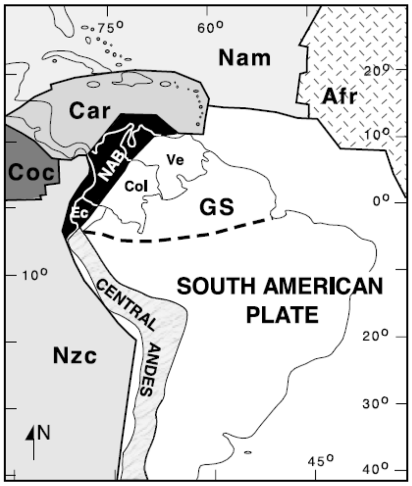


Figure 1. Tectonic framework of northwestern South America. NAB = Northern Andean Block; Car = Caribbean plate; Nzc = Nazca plate; Coc = Cocos plate; Nam = North American plate; Afr = African plate; GS = Guiana Shield; Ec, Col, Ve = geographic limits of Ecuador, Colombia and Venezuela, respectively.

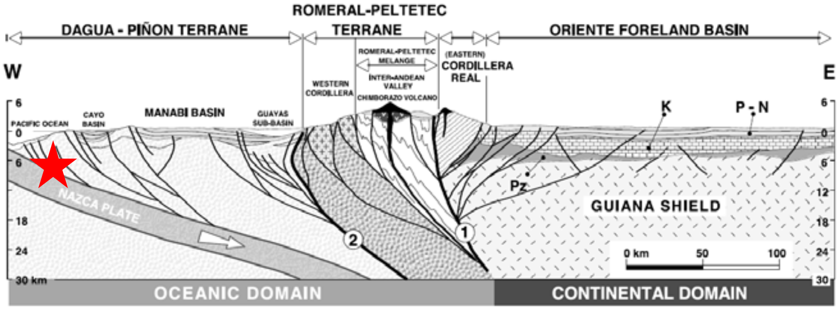


Figure 5. West-east transect across the Ecuadorian Andes. Modified after National Geological Map of the Republic of Ecuador, Ministerio de Recursos Naturales y Energéticos (CODIGEM, 1982). Principal sutures: 1 = Romeral-Peltetec fault system; 2 = Cauca–Pujilí fault system. Pz = Paleozoic; K = Cretaceous; P = Paleogene; N = Neogene.

Reference: *Cediel, F., R. P. Shaw, and C. Ca´ceres, 2003, Tectonic Assembly of the Northern Andean Block, in C. Bartolini, R. T. Buffler, and J. Blickwede, eds., The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics: AAPG Memoir 79.*

Ecuadorian Building Construction and Code

Building Construction

The primary construction material in Ecuador, as in most of South America and the Mediterranean region, is non-ductile reinforced concrete with single-Wythe brick block or terra cotta perimeter infill and partitions. This construction is similar to some of the early concrete buildings seen in the U.S. dating back to the 1920's and 1930's and still a large part of the building inventories of many U.S. cities. This type of "light" concrete framing with thin brick/tile infill construction is very similar to the non-ductile 5-7 story "besket" buildings that were responsible for numerous building collapses and casualties in the tens of thousands in the 1999 Izmit, Turkey Earthquake. The continued use of undersized columns can be noted even in newly constructed Ecuadoran residential structures, and in major structures at the upper level(s).

The function of the brick/tile infill in Ecuadorian construction is primarily as an exterior partition or enclosure only, or for non-structural interior partitions, and is of comparatively low strength. This is not the "confined brick" used in other countries such as Peru where brick infill has appreciable strength and is designed to provide lateral strength for wind and seismic forces.

Unique to Ecuador is the very common use of brick infill laid in between wood floor and wall framing, which was frequently observed in buildings less than three-stories tall, but was also observed in some of the taller buildings. The wood species utilized in Ecuadoran construction, especially at the exposed beams (laurel, cedro, Fernan Sanchez) and columns (moral, guayacan), is apparently highly resistant to weathering and rot, since the construction in conjunction with brick/tile infill can be seen throughout the country without serious adverse effect from weathering (at least in the short-to-medium-term). Some older residential structures utilize bamboo lath and plaster exterior finishes instead of brick/tile infill. Minor structures, less than three stories high, often include cantilever reinforced concrete columns fixed at grade that support wood floor framing at the upper levels.

In rural areas it is common the use non-engineered construction with expected marginal seismic performance.

A few modern steel structures that were currently being constructed were also noted in Guayaquil and Quito (the capital). Other structures included steel telecommunication towers and airport facilities.

Ecuadorian Building Code

The current building Code in Ecuador is the **Norma Ecuatoriana de Construcción (NEC-2011)**, which was initially published in 2011 for general discussion, then officially adopted and enforced in the beginning of 2015. The seismic regulations in NEC-2011 follow the International Building Code (IBC) and the NSR-10 (Colombian Code). The reinforced concrete design regulations follow the American Concrete Institute's code (ACI-318), whereas the structural steel design follows the American Institute of Steel Construction (AISC) requirements. The NEC-2011 Code also requires approval of the construction documents before issuing construction permits by the Municipal authorities.

The NEC-2011 replaced the previous Ecuadorian Code, INEN-2001, developed by the INEN (National Institute of Norms). The seismic regulations in the 2001 code utilized a 475-year design earthquake for design, and the seismic design criteria was "Life-Safety".

Previous regulations and construction standards (standards are not enforced) appear to be the CEC-77, which followed closely the 1976 Uniform Building Code (UBC). These "standards" were intended to be applied to concrete frame structures. The major Ecuadorian City of Guayaquil later developed a local code that followed the 1997 UBC for earthquake design, but with modifications to the seismic mapping suitable for the Guayaquil region.

One of the main problems with the applications of the Construction Code was/is the lack of the enforcement and lack of inspection during construction. Actual construction is often performed without qualified engineering supervision.

General Building (Residential and Commercial) Damage Observations

The following are general observations, which were similar in Residential as well as in Commercial buildings in the areas visited by ABS Consulting's reconnaissance team. The majority of the buildings we observed were of reinforced concrete construction with brick or tile infill walls.

Influence of Brick or Tile Infill Walls

Despite its weak nature, the Ecuadoran brick/tile infill is still rather stiff when loaded in plane and provides both incidental lateral strength and stiffness at the locations where it is provided. Even when uniformly distributed over all stories of a building, the presence of brick/tile infill walls is problematic during earthquake shaking. Invariably, the brick infill at one level is more heavily stressed by the earthquake than at other levels and begins quickly to loose strength. In this condition, the floor levels above and below the more heavily stressed and are substantially stronger laterally than the level where damage has accumulated, since their infill in still intact. This concentrates the lateral displacements to the cracked level and the building's non-linear behavior to only this one level, rather than distributing it throughout the building height. Stiffened by the infill above and below, the floor slab cannot yield appreciably, which results in a collapse-prone lateral column yielding mechanism. Once a column yielding mechanism is created, a partial or total building collapse is very likely, with collapse eminent in the case where ground shaking continues. The only real way to prevent these mechanisms in brick-infilled concrete frame buildings is to provide larger columns of substantial strength that are capable of forcing the lateral story yielding into all of the levels of the building, even if brick infill is present or missing/damaged at certain levels.

Undersized and Non-ductile Columns

Ecuadorian reinforced concrete columns are generally square or nearly square in cross section and extremely small by proportion when comparted to similar construction in most industrialized countries. In fact, the bulk of the buildings we observed in Ecuador, except for newer tall buildings and major structures, are dominated by very small column cross-sectional dimensions on the order of 8 inches to 10 inches (200mm to 250mm). Rebar detailing in most of the older buildings can be considered extremely non-ductile in that, besides having small column dimensions, column ties are also small (less than #3 or 10mm diameter), widely spaced (tie spacing vs. column width, s/h = 0.75), and lacking modern seismic bends and cross-ties. In addition, the use of smooth (undeformed) reinforcing bars that are incapable of preventing the development of large concrete cracks is not uncommon.

Once the 1.5 inches (38mm) thick unreinforced concrete cover on the small non-ductile columns spalls during earthquake shaking (as observed), very little of the concrete core of the column remains to support the buildings, with catastrophic results that results in subsequent loss of vertical supports. For example, for a 10 inch (250mm) square column, the remaining area after spalling is only 49% of the pre-spalled condition; for an 8 inch (200mm) square column, the remaining area after spalling is only 39% or the pre-spalled condition. This area of concrete would be applicable only if the columns were well confined with closely spaced ties (which they typically are not). *As a relative comparison, the minimum column dimension currently specified by ACI 318-11 for regions of high seismicity is 12 inches (300mm), which after cover spalling, would leave 56% of the pre-spalled concrete area for well confined columns (i.e. columns having complying closely spaced ties and cross ties).*

Material Deficiencies

Other common structural deficiencies observed were related to the construction materials and included severe rusting of reinforcing steel and the obvious low strength of much of the concrete (which was seen to be easily chipped by workers using hand tools). The use of beach sand for aggregate may be a likely reason for these deficiencies with the rebar and concrete strength, but this possible source is speculative at this point and is in need of further evaluation.

Floor Slabs

Floors generally consist of 8 inch (200mm) thick flat reinforced concrete slabs, or somewhat thicker waffle slabs, with or without brick forming for the "voids" left in place. These slabs appear to be fairly well detailed and interconnected to the columns, and are capable of developing tremendous ductile behavior well beyond yielding and initial strength loss, as no structural collapse directly associated with slab behavior was observed. Most of the foundations we observed either were spread or wall footings, although for taller structures it is presumed that piles were utilized.

Adjacency & Interaction between Buildings

Structural interaction with adjacent structures (known as adjacency) is another area of concern related to seismic safety. Very common in Ecuadorian construction is the lack of a separation joint of more than a few millimeters, if at all, between adjacent buildings. Also at adjacent buildings, there is no code requirement that the adjacent floors align vertically in any manner. These conditions have in the past (during the Kobe Earthquake) contributed to total and partial building collapses, especially at buildings located at the end of a line (i.e. street corners) or taller buildings adjacent to shorter buildings, as the buildings impact each other and impart energy that neither buildings nor their columns, designed as a stand-alone, are designed to resist.

Damage to Commercial Buildings (Selected Case Examples)

Manta: Pacific Hotel & Adjacent Bookstore (MMI VII)

Undersized and poorly detailed columns, adjacency and a vertical irregularity associated with mixed building height are the likely reason for the partial structural collapses of the Pacific Hotel and the complete collapse of the adjacent bookstore to the north. Cumulatively, these building collapses are responsible for killing over 96 people. Note that the floor slabs performed very well, yielding in a very ductile manner well into the non-linear range, while supporting a tremendous amount of weight from the collapsing building.

(*It should be noted that during our reconnaissance, all of the building collapses that we observed were directly due to loss of column vertical strength). ABS Consulting observed very few flat slab punching shear strength loss mechanisms. For the few floor slab punching shear mechanisms we saw, all had been severely overloaded by structural debris falling from above and all still retained some residual strength consisting of "hanging" slab column-strip reinforcing steel. This column-strip steel, while severely damaged in many cases, prevented the total loss of vertical support of the floor*).

In the case of the Pacific Hotel, column failure due to undersized columns and a lack of rebar tie confinement at the top and bottom of the columns was the primary mechanism for the hotel collapse. Luckily, the adjacent building to the south was constructed with columns having greater cross-sectional dimensions and was able to laterally support both itself and the toppling Pacific Hotel as well, thereby protecting many other lives. The Pacific Hotel lost four (4) intermediate stories due to partial collapse.

Manta: Chifa La Rosa Restaurant (MMI VII)

The Chifa La Rosa Restaurant building is a four-story non-ductile concrete structure with small columns located on an oblique street corner. The building is also trapezoidal in plan. These aspects alone would make the building highly susceptible to seismic damage and collapse during the strong earthquake ground shaking experienced in Manta. However, the building experienced very little observable structural damage.

Contrast this with the building across the street, also four-stories with undersized non-ductile columns - this building experienced a devastating partial collapse. Why did this building collapse and the Chifa La Rosa remain standing? Upon closer observations, the Chifa La Rosa Building Owner had retrofitted the building by widening the columns, adding nearly double the column area to the lower level. The reason for the column widening is unknown and may have been related to the addition of another floor level as opposed to as a seismic retrofit. *While this building retrofit is hardly a textbook example of quality by U.S. standards, we believe this is a great example of the benefits of actual/accidental seismic retrofit versus the "do nothing" alternative. The example also supports the assertion of these writers that undersized concrete columns were a fundamental reason for the numerous devastating structural collapses during the M7.8 Ecuador Earthquake.*

Note that the damage to the newer 4-story building with the mansard roof parapet to the left was also minimal. This building was constructed using improved standards and had significantly wider columns.

Manta: Various Partial Building Collapses (MMI VII)

Throughout the closed city zone there were several graphic examples of partial or impending story collapses at the intermediate or ground floor levels of buildings. All were characterized by the presence of undersized columns, by stepping column sizes down too quickly, or infill or adjacency issues related to impact from adjacent structures.

Portoviejo: Nine-Story Office Tower (MMI VII)

Lacking an adjacent building to create any interaction hazards, the cause of structural failure of the three intermediate floor levels (4-6) of this relatively modern nine-story building is obviously directly associated with the building's structural system. The failure is most likely related to critical damage to the short-captive columns (maroon colored) located at the reentrant corners. These "short" columns pull in substantially more lateral forces than the other non-captive columns at the floor level and are created by the placement of brick or concrete window wall cladding in direct contact with the column (red arrow added to the photo). Other contributors to the collapses include the likely stepping down (above the 3rd level) of the generally wide circular columns seen at the building base and interaction with the stiff interior brick partitions. The second mode vibrational characteristics of the building may have been amplified by the shaking at this location as well. Despite the easily noted eccentricity created by the story collapses, the structure was able to remain standing. Note the man-lift operator working in the vicinity despite the obvious potential danger.

Esmeraldas*: Hotel Colon (MMI VI)*

Hotel Colon is a modern five-story reinforced concrete building with brick infill walls and partitions located near the civic center. The hotel was one of few major structures in Esmeraldas to exhibit any notable earthquake damage and, as a result, was not occupiable. Interior and exterior partition walls at the lower three stories showed readily observable diagonal earthquake X-shaped cracking and there was obvious damage to the exterior metal cladding and window glazing systems. However, the reinforced concrete columns were notably large by Ecuadorian standards and the column-flat slab structural frame was undamaged except for minor plaster spalling. Repair work at the time of ABS Consulting's observations were ongoing, with concrete stiffened brick elevator enclosure walls and partitions in the process of being reconstructed. Despite the lack of major structural damage, the downtime due to damage of non-structural elements for this locally high-end lodging facility is obviously significant.

Tonsupa: High-Rise Residential/Hotel Towers (MMI VII)

Located in the region of Ecuador having the highest ground shaking intensity is the region of Atacames/Tonsupa. Despite the estimated 0.35g of peak ground acceleration by the M7.8 coastal earthquake (as listed on the USGS maps), Atacames/Tonsupa experienced very little damage to its buildings. Modern high-rise buildings being potentially wind-controlled and on piles would be expected to experience less earthquake damage. However, even the older two to six-story structures located in the older sections of this area experienced little damage. Looking at the exposed portion of the steep but low sea cliff, it appears that the soil here is largely dense clay with some cobbly alluvial lenses, which may have been a factor. Considering the low volume of earthquake damage in this area, it is questionable that the shaking was as high as MMI=VII, and was probably closer to MMI=VI. Despite having almost no damage, the resort area was experiencing a significant reduction in occupancy since most Ecuadorians were afraid of collapses due to aftershocks.

Damage to Residential Housing (Selected Example Case)

South of Pedernales: Family Residence (MMI VIII)

Undersized and poorly detailed columns and a non-uniform arrangement of interior and exterior block masonry partitions are the likely reason for the partial structural collapses of this new three-story home. The upper “living space” levels were laid out with multiple brick partitions to create room separations, whereas the lower ground level was largely “open”. While not directly considered on the structural analysis, these brick partitions provide for substantial strength and stiffness, making those floors with notably less partitions weak and flexible in comparison. Once the brick partitions loose strength at a particular level, only the undersized columns remain at that level to laterally support the building during earthquake shaking. The undersized columns provided were too weak to force any desirable yielding to occur at the adjacent or upper levels, which forces a yielding/strength loss mechanism into the columns at that level. After a few displacement cycles with poor non-ductile detailing in the undersized columns, vertical strength loss in the columns began, and loss of vertical support and collapse at that floor level was eminent.

Note again that the “waffle” floor slabs performed very well, yielding in a very ductile manner well into the non-linear range, while supporting a tremendous amount of weight from the collapsing building.

Damage to Residential and Commercial Buildings

Pedernales: Widespread Damage & Collapse (MMI VIII)

Located on rolling hills approximately 26 kilometers from the epicenter, the community of Pedernales was devastated by the earthquake ground shaking. Many of the recoded deaths occurred in this area. As opposed to other areas to the south that had localized damage zones (closed zones) that fell into more or less construction vintages or presumed soil types, the entire Pedernales region was devastated. In reality, the whole town was a “closed zone”. Building collapses and ground and foundation failures were widespread, occurring near the beachfront, on hillsides, and hilltops alike, mostly to older structures, but in many cases brand new buildings under construction or nearing completion. Based on what we saw, 100% of the structures in this city experienced damage, mostly extensive and a large fraction of the taller or marginal structures outright collapsed at one, multiple, or all floor levels.

Some very light traditional lightweight Ecuadorian residences on cantilever columns survived with surprisingly little damage.

Many of the non-ductile concrete resort hotels along the beachfront strip collapsed and the roadways still bear the ground ruptures that resulted from the pressure wave created from their collapses. Some are in still standing but are in the process of toppling, leaning precariously towards the downhill side. Still in the clearing stages of much of the rubble, the community is starting to rebuild. However, the damage is so extensive that this earthquake will likely have an impact for decades.

According to the shaking mapping in USGS report, the peak ground acceleration in Pedernales was on the order of 0.37g. The local and federal police had a strong presence throughout and UNICEF had set up at least two large relief camps.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Damage to Industrial Facilities

Portoviejo: Grain Storage Facility (MMI VII)

Earthquake related damage to several cylindrical corrugated-metal steel-framed grain storage silos on legs was observed. In this case, the support of all four silos closest to the grain elevator building failed. While the reason for the collapses of these particular silos is uncertain, a buckled leg was observed (see photo). Based on our observations, it is probably likely that these silos were partially full, while the other silos still standing and mostly undamaged were mostly empty. Based on damage to the anchor bolt connections at the base of the legs and some buckled legs (see red arrow), the silo failures were most likely due to a combination of anchor bolt failure on the uplift side and then leg buckling on the compression side under seismic lateral overturning forces.

The grain elevator building and ancillary storage building structures were mostly undamaged, except for some damage to the brick infill and lightweight roof related to frame racking and collapsing silos. The silos fell down away from the elevated conveyor lines, which sagged, but somehow did not fall.

Damage to Government Buildings and Other Public Facilities

Several Government office buildings and Public facilities in different cities experienced different level of damage due to the earthquake.

In Portoviejo (MMI VII) a brand new Government reinforced concrete building in the Manabi district suffered extensive brick infill wall damage as well as column structural damage. It appears that soil soft conditions at the building site contributed to the damage.

A five-story concrete city government office building in Pedernales (MMI VIII) suffered extensive damage to brick infill walls and window glazing.

In Guayaquil (MMI V), a reinforced concrete building for the Ministry of the Interior (located in the Avenida de Las Americas) experienced brick infill wall damage. This damage may be the related to locally-occurring soft soils in the area that possibly amplified the shaking.

In Esmeraldas (MMI VI), a three-story reinforced concrete-frame/shear wall city government office building suffered minor brick infill partition damage. The building appears to have adequate sized columns and beams.

In Pedernales (MMI VIII), an older reinforced concrete stadium that was constructed with substantial column and beam framing and a light steel framed roof had little structural damage, except for an unreinforced masonry press box.

Other light and tall structures, such as steel communication towers had long vibrational periods and appeared to be intact.

Damage to Transportation

Traffic Overpass in Guayaquil (MMI V)

Photo of Collapsed Overpass: AgenciaAndes - http://www.flickr.com/photos/75116651@N03/25878141753/, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=48234717

A portion of the reinforced concrete overpass on the Avenida de Las Americas in front of the University Vicente Rocafuerte and near the airport collapsed. Another section of the same bridge suffered damage but did not collapse, and is shored awaiting repair. This overpass was constructed circa 1980 and is a prominent component of the main connection between the North and Central areas of Guayaquil. At least one causality is attributed to the collapse. Based on photographs taken by others immediately after the earthquake, the collapse appears to be related to an initial stability loss at the shorter bridge buttresses, which toppled in the parallel to roadway direction. The failure of this bridge is surprising because the ground shaking intensity in Guayaquil (280 kilometers from the epicenter) was only MMI V (approximately 0.07g).

Interestingly (and as indicated before) the only other notable earthquake damage we observed in Guayaquil was some brick infill damage at the Ministry of the Interior building directly adjacent to the overpass. This may be potential evidence of some locally occurring soft soils in the area that possibly amplified the shaking.

Bridge and Roadway Embankment Damage
Highway between Muisne and Esmeraldas (MMI VII to VIII)

A small bridge on the route between Muisne and Esmeraldas collapsed during the earthquake ground shaking and had been replaced by a temporary steel bridge. It is suspected that the bearing supports on the embankment on one side of this bridge failed during the earthquake.

Along this route, ABS Consulting noted numerous minor settlements to roadway embankment "fills", especially predominant at valleys where the bottom of the "vertical curve" roadway layout occurs, and at bridge transitions.

Soil Failures & Landslides

Signs of soil liquefaction, soil failure associated with high water table, and possible soil settlement were observed at the coastal cities of Manta, Pedernales and Muisne. Some of the soil disruption noted along the oceanfront road in Pedernales (MMI VIII, photos below) may have been exacerbated by the impact force and created "soil wave" associated with the total vertical collapse of two large beach-front hotels that have been subsequently demolished.

Small landslides at some roadway cuts were observed while driving the ocean highway between Manta and Pedernales.

Lessons Learned from the Earthquake (Preliminary)

Damage of structures, especially reinforced Concrete Buildings, are associated with the following deficiencies:

Vulnerabilities

1. Predominance of the use of undersized columns less than 300 millimeters in width that are not suitable for use in seismic regions. After the initial spalling of the cover during ground shaking induced lateral building displacements, there is not sufficient concrete to support any magnitude of imposed vertical building loads.
2. Poor concrete confinement and detailing: small and coarsely spaced ties were common on damaged and collapsed structures. The ties do not satisfy the current seismic code requirements in regard to spacing or bending.
3. Adjacency effects: column crippling and impact due to interaction (impact) with adjacent structures, especially with those having different floor heights.
4. Effect of brick and terra cotta infill was not considered in the design. This resulted in that weak story mechanism developed and often story collapse.
5. Inadequate lateral support of infill walls for out-of-plane forces.
6. Building irregularities such as weak stories, hill-side structures, short-captive columns
7. Vulnerable older vintage, non-ductile concrete structures have not been seismically retrofitted.
8. Use of a marginal building seismic system predominates the construction: slab-column frames with brittle rigid infill

Materials

9. Low strength or deteriorating concrete. Use of sand beach in coastal areas contribute to the low quality of concrete.
10. Severely rusted concrete reinforcing steel (rebar) with spalling and loss of significant cross-sectional area. In addition, it is typical to leave column rebar extensions unprotected in anticipation of future building expansions (i.e. story additions)

Construction Practice

11. Lack of Soil Investigation: it is likely that soil investigations are not performed and therefore foundations are not designed for the appropriate soil conditions.
12. Engineering: it is evident that many building constructions, especially those residential housing, are performed by unqualified (non-engineer) personnel to save money.
13. Lack of code enforcement and inspection: this is especially valid in remote areas, where construction is done in areas (site conditions) not appropriate.
14. Construction and quality assurance practices during construction are likely poor.

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