EARTHQUAKE HAZARD CENTRE NEWSLETTER

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Contents

Editorial: The danger of brick partition walls

On 16th April 2016, Ecuador was struck by a 7.8 magnitude quake. As one might expect, lives were lost, people were injured and the damage to buildings was extensive. In the city of Manta, for example, 12% of the population were displaced from their damaged or destroyed buildings.

This newsletter focuses on the building damage from that earthquake as the prevalent types of construction in the affected area are common in many developing countries. Many low-rise buildings, around four storeys high, are constructed of RC frames with unreinforced masonry infill. Masonry cladding and partition walls are common, and lightweight alternatives the exception. The three main articles then all report on the building damage in Ecuador. They have been sourced from and summarize "EERI Learning from Earthquakes Briefing Webinars". The full presentations can be downloaded from the EERI website.

Since the source material consists of the slides used in the webinars, we have based our articles on the same material, but unlike previous articles little text and many images are included. To a large extent the images, often annotated, speak for themselves, but the greatest reminder or learning from this earthquake is the poor performance of unreinforced masonry cladding and partition walls. Damage to such elements is seen and commented on after most earthquakes, but these reports highlight it.

It shouldn't surprise us that we are asking for trouble when within quite flexible frame structures we insert very stiff, brittle, weak, heavy and tall elements. During an earthquake inter-storey horizontal deflections of frame buildings are in the range of tens of millimetres, say from 20 – 70 mm. But masonry cracks at only 10% of these displacements. And once it cracks, its bending strength is lost.

In Virtual Site Visit No. 42 of the April 2016 Earthquake Hazard Newsletter we discussed reinforced concrete infill frames and suggested that if the infills are not separated from the frames, a better structural system to use is confined masonry. It was noted that where the infills are not physically tied to structural elements they can collapse from or into the building. The damage in Ecuador illustrates exactly this sort of damage, but often the damage and collapsed masonry was not infill between structural columns, but cladding or wall partitions. Some brick walls were just screening services. In many buildings tremendous damage occurred to cladding and partitions.

The articles in this newsletter emphasise the danger posed by these unreinforced walls. The damage from this earthquake presents a challenge to building industries situated in seismic zones. The use of unreinforced masonry walls needs to be phased out. Either the masonry needs to be reinforced or replaced by lighter weight alternatives, such as gypsum plasterboard. There are numerous methods to reinforce masonry walls, including practical columns, internal reinforcement and reinforced plaster coatings, but lighter alternatives reduce the seismic loads acting on buildings.

The main lesson from this newsletter therefore is that, due to their danger in earthquakes, unreinforced masonry walls need to be replaced by safer options.

Virtual Site Visit No. 43 Reinforced concrete moment frames

In this site visit we observe the construction of an eight-storey reinforced concrete car parking building at Wellington Airport, Wellington. Moment frames have been chosen as the seismic load resisting structure. They allow for the freedom of placement of entries and exits into and from the building as well as for internal vehicular circulation and parking. An overall view of the site is shown in Figure 1.

Given the location of the building in one of New Zealand's most seismically-active areas, not only does its structure need to be strong to resist the inertia forces of a severe earthquake, but it needs to be ductile. To achieve the openness of structure required by the architectural program, like all buildings designed to most seismic codes internationally, the design forces are less than those expected to occur during the Big One. Hence the need to accept structural damage and design for ductility.

The strongest members of a ductile moment frame must always be the columns and never the beams! Columns support the entire weight of a building, so if they are badly damaged then partial or full collapse of the building is likely. The design philosophy, known as Capacity Design, requires first of all for the columns to be stronger in bending than the beams framing into them. Secondly, the shear strength of each column must be greater than its more ductile bending strength. Finally, the reinforcing must be detailed in such a way as to allow some damage but to prevent any significant loss of strength. We can see these design concepts applied in the context of a single column (Figure 2).

The column is obviously very strong in bending as a consequence of the large number and size of longitudinal bars. The square cross-section of the column and the well-distributed longitudinal reinforcement around its perimeter suggests this column is part of a two-way frame. In this case the column will be subject to bi-axial bending. As well has possessing high bending strength, the shear strength is also very high throughout the entire height of the column. Ties are closely-spaced and at each level of ties, eight legs pass through the column. The legs not only contribute to shear strength, but also prevent the longitudinal steel bars buckling when the cover concrete is lost during a damaging earthquake. Note that the ties all have 135 degree bends to maintain effectiveness even without cover concrete. See if you can find where the steel fixers have left out a tie!

Figure 1: A view of the site

Figure 2: Column reinforcing

Although moment frames are often a great architectural choice, they do require sophisticated and relatively expensive design, detailing and construction to ensure adequate ductility and seismic performance. Post-earthquake repair may also be difficult depending on the severity of damage.

Summary of Damage Observed in Tarqui, Manta

The full presentation can be obtained from the April 16, 2016 Ecuador Earthquake EERI Learning from Earthquakes Briefing Webinar by Mei Kuen Liu of S.E. Forell / Elsesser Engineers

Manta - Introduction

- 20 miles from Portoviejo
- Population 221,000
- 5th most populous city in Ecuador
- 4-5 storey RC frame building with masonry infill walls
- Many residential builldings or hotels with retail on ground level
- Typical floor extends over sidewalk

Manta - Observed Damage

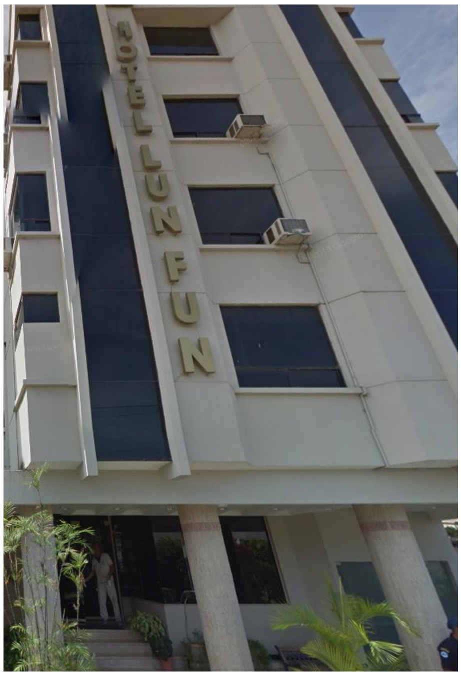
Hotel Vista Alegre

- 5-storey RC frame building with masonry infill walls
- Extensive wall damage
- Walls fell out after in-plane failure

Hotel Vista Alegre

Hotel Lun Fun

5 storey RC frame building with masonry infill walls.



Before earthquake.
Higher ground floor height to soft storey.

After earthquake. Note rectangular column on typical floor but circular on ground floor.

Poor concrete quality. Unreinforced masonry wall not braced. Inadequate concrete confinement. Note rectangular rebar cage for round column.

11th Ave and 2nd St

4 storey RC frame building with masonry infill walls.

Before earthquake. Note typical floor hangs over sidewalk. Higher ground floor height soft storey.

After earthquake
Complete collapse of ground level.

11th Ave and 2nd St

108th Ave and 102nd St

4 storey RC frame building with masonry infill walls; roof conversion.

Before earthquake. Higher floor height - soft storey.

After earthquake. Storey collapse.

Main Causes of Damage

Similar to Portoviejo
Extremely flexible RC frame buildings with heavy unreinforced masonry fill walls.
Inadequate concrete confinement for columns.

More specific to Manta
Building geometries lead to soft storey behaviour.

Summary of Performance of Hospitals

The full presentation can be obtained from the April 16, 2016 Ecuador Earthquake EERI Learning from Earthquakes Briefing Webinar by Adrian Tola T. of Virginia Tech at www.eqclearinghouse.org

Structural System
Typical:
• Concrete Moment Frames at all bays (not just at the perimeter), with concrete "waffle" slab
• Concrete Moment Frames (particularly at the exterior bays) are usually infilled with unreinforced masonry (URM)
• Interior partition walls are also made of URM, with very week attachments to resist out of plane forces

Hospital IESS (Manta)
• Severe cracking or total collapse of several interior and exterior walls made of unreinforced masonry
• Lack of proper attachment for mechanical equipment

Hospital IESS (Manta)

Hospital Miguel Hilario Alcivar (Bahia)
• This hospital was retrofitted in 2000 after a M7.2 earthquake in Bahia in 1998
• Part of the seismic retrofit included the cast of 6 shear walls, and jacketing of some concrete columns at the perimeter

Front view. Shear wall marked.

Lateral view. Shear walls marked.

Severe cracking of URM walls was observed in the 1st floor; however, several off these walls did not fall down towards the ground. Smaller drifts due to rigidity of shear walls might have influence on this behaviour?

No attachment of partition wall

Hospitals - Conclusions

• Poor performance of interior/exterior URM walls. Major damage was concentrated at the first two stories for multi-storey building segments, with the exception of the Hospital IESS in Manta, where all the stores had poor behaviour of URM

• Minor damage observed in structural system (beams & columns)

• Good performance of seismic retrofitting techniques, as observed in the Hospital Alcivarin Bahia

• Damage caused by inadequate separation at seismic joints could have been avoided

Summary of Partitions and Cladding of Multi-storey Buildings

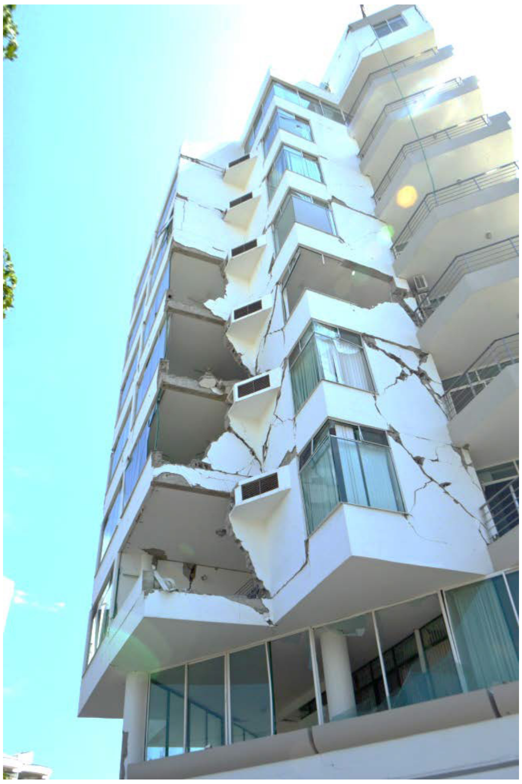
The full presentation can be obtained from the April 16, 2016 Ecuador Earthquake EERI Learning from Earthquakes Briefing Webinar by Hector Monzon of AGIES - Guatemalan Society of Structural Engineering at www.eqclearinghouse.org

In Summary

- Partitions and cladding were generally made of masonry
- Their seismic performance was not satisfactory
- Reason:
  - too stiff as compared to the frames
  - inadequately fixed to the structure
  - scarcely reinforced or not reinforced
- Gypsum board is seldom used
- More flexible or panelled facades are not used

About Multi-storey Buildings in coastal area

- Generally buildings are RC up to 10 storeys older units: flat slabs or waffle-slabs on columns newer units: girder-column frames, RC floors shear walls are not used
- Building occupancy in coastal area: apartments / hotels hospitals government buildings few office buildings



About materials partitions and cladding

- Generalised usage of masonry not reinforced very scarcely reinforced
- 2 main types:
  - hand-compacted artisanal baked clay bricks
  - blocks (standard size) concrete or cement-mortar
- sometimes
  - extruded hollow clay units (thin walled horizontal cells)

Performance of masonry cladding

- Due to inadequate anchorage to main structure masonry cladding frequently toppled and fell to the ground
- Or else due to lack of reinforcement cladding disintegrated
- Cladding failure is of course, a very serious threat
- Both at ground and for the inhabitant
- Again, due to lack of reinforcement and inadequate anchorage to main structure

Blocked Means of Egress

- In several instances it was fortunate that the earthquake was Saturday evening

At the root of the performance problem

- Masonry partitions and cladding are brittle and too stiff for the typical building
- This type of masonry starts to crack with a few millimetres of in-plane story displacement while the "typical" building frame can be shown to start yielding at 2 cm inter-storey displacements
- If the masonry is under-reinforced it disintegrates at the design EQ loading
- Even if partition is permitted to "slide" while prevented from toppling it is usually very difficult to achieve effective displacement isolation
- For claddings a more flexible system or a panelled solution is necessary
- But before trying to "perfect" or "rescuing" the masonry system there is a more fundamental step to take

As a conclusion the "typical" structure is too flexible

- For the architectural usages in Ecuador and other Latin American countries stiffer structures are needed.
- It is necessary to use resources such as shear walls to laterally stiffen the buildings (and to increase strength reliability)
- In the presenter's view, only when stiffer structures are built should the issue of proper non-structural seismic design be addressed
- It is not only the partitions and cladding which are threatened by too flexible structures, hanging ceilings are a threat, especially in large, high rooms

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

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