1. INTRODUCTION

On February 19, 2015 Build Change, represented by Juan Caballero, Lizzie Blaisdell and Hector Romero Toro, visited six schools in the districts of San Marcos (four) and Quetzaltenango (two), Guatemala. See Figure 1 for the location of the two cities in Guatemala. These schools had been damaged by either or both of the recent earthquakes in the area; some had or were receiving some form of repair while others still remain in their post-earthquake damaged state. The intent was not to perform detailed evaluations of each school during the visit, but instead to get a better understanding of the schools each municipality may need technical assistance with, what their construction styles are and what the potential deficiencies may be.

This report summarizes the observations made at each of the visited schools, identified potential deficiencies as well as possible retrofit strategies.

Figure 1 – Map of Guatemala with San Marcos and Quetzaltenango (Google Earth)

2. RECENT SIGNIFICANT EARTHQUAKES IN THE REGION

On November 7, 2012 a M7.5 earthquake significantly affected the region, with damage and economic losses exceeding USD 128 million. The epicentral location of the earthquake was off the Pacific coast of Guatemala; however the strongest shaking and most severe damage was felt inland, in the San Marcos and San Pedro areas. Then in on July 7, 2014 another strong earthquake, M6.9 (centered on the Mexican coast just north of the Guatemalan border), affected the region; causing further damage to the buildings weakened by the previous earthquake.

3. SCHOOL OBSERVATIONS

3.1 INSTITUTO NACIONAL DE EDUCACION BASICA EXPERIMENTAL "MARIA CRISTINA BARRIOS"

Location: Calzada 25 de Abril, Zona 5, San Marcos
Site visit host: Habitat for Humanity Guatemala
Number of students: 502
Building types and status: Confined masonry - damaged, undergoing repairs

General Description

The school is located on flat land. It consists of multiple independent confined masonry buildings. The administration building is two-stories tall (Figure 2) and the classroom buildings are one-story (Figure 3). The roofs are composed of light-gage steel tubes or channels with corrugated metal roofing. There is a reinforced canopy structure covering the walkways between buildings; this is shown in both Figures 2 and 3.

Figure 2 – Administrative two-story building

Figure 3 – School Building with covered walkway in front

Damages Observed

In several buildings, the existing walls showed signs of shear cracking in the earthquakes. In most cases, these cracks had been repaired (Figure 4) or the wall had been rebuilt. Some buildings had experienced roof failures, and were in various states of repair (Figure 5).

Figure 4 – Repaired wall cracks

Potential Seismic Deficiencies

- Lack of longitudinal shear walls – The longitudinal classroom walls consisted primarily of window openings which reduces the lateral strength and stiffness of the building in the longitudinal direction (Figures 5 and 6). In some buildings a solid wall panel was provided at the end of the longitudinal wall elevation (Figure 3) but in other buildings it was not.

Figure 5 - Typical Longitudinal Wall and Elevation at the Classrooms

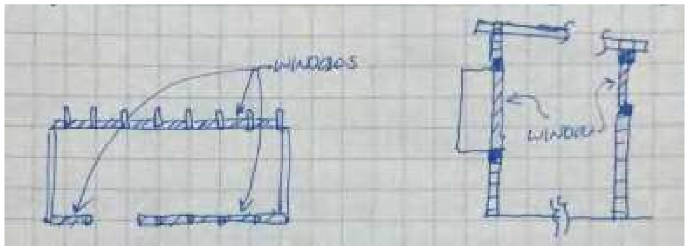

Figure 6 – Sketch of typical classroom floor plan and section

- Lack of upper confining beam – Along the taller longitudinal walls (aligned with the top of the sloped roof), an additional ring beam was not installed and so the masonry block above the window sill (block that supports the roof) is more susceptible to out-of-plane failure.

- Short column/pier condition – Typically one longitudinal elevation had a high row of short windows. These windows were continuous, with period vertical posts and with only one solid panel, located above the door. (Figure 7) This solid panel was typically where the damage was concentrated. As the most rigid load path from the roof to the solid wall below the widows, it attracted higher earthquake forces and failed. These were being repaired in several classrooms to the pre-damage state and so failure in a similar way would be expected in future earthquakes. These seem particularly dangerous as they are located over the exit – which is exactly where students would be heading in the event of an earthquake.

Figure 7 – Repaired short pier above door (left) and existing pier (right)

- Walkway canopy - There are structurally independent walkway canopy structures composed of reinforced concrete moment frames (Figure 8). These structures failed at the top and bottom of the columns. Repairs have been made, but strengthening or the addition of bracing to prevent future failure in the same way has not been performed, so it is reasonable to expect similar or likely worse, performance in future earthquakes.

Figure 8 – Repaired concrete frame canopy structure

Potential Retrofit Strategies

- Infill some windows and add confining elements as needed to create more solid wall panels in weak direction.

- Provide a upper ring beam adequate for spanning between cross walls

- Remove short solid panel above door opening (solid wall panel infilled elsewhere)

- Supplement wall strengths as needed (double walls, reinforced concrete overlay)

- Demolish heavy concrete frame canopy. Replace with a light weight structure if necessary.

3.2 INSTITUTO NACIONAL DE EDUCACION BASICA (INEB) JUSTO RUFFINO BARRIOS

Location: 14 Calle Final y 34 Avenida Zona 21, Colonia Justo Rufino Barrios
Site visit host: Habitat for Humanity Guatemala
Number of students: 520
Building types and status: (3) Concrete moment frame with masonry infill - damaged, unoccupied; (1) confined masonry – repaired, occupied

General Description

The school is located on a gently sloping site. It consists of three independent two-story reinforced concrete frames with masonry infill buildings (Figure 9) and one two-story confined masonry building (Figure 10). The concrete frame buildings are arranged in a U-shape around central courtyard and have a small seismic gap separation between each other (Figure 11). There also appeared to be a foam material around the perimeter and separating the infill panels from the frame structure. These buildings have concrete slab roofs. The confined masonry building has a light weight roof framed with shallow steel trusses. The stair bay at one end appeared to be an independent adjacent structure.

Figure 9 – Concrete moment frame building

Figure 10 – Confined masonry building

Figure 11 – Seismic joint between concrete frame buildings – mortar-covered & foam-filled

Observed Damages

The confined masonry building had been repaired and appeared to have thicker wall piers between windows. The reinforced concrete frame buildings were still in their damaged state. According to the school principal, the first earthquake caused cracking at the infill panel edges (Figure 12) and the subsequent earthquake led to some cracking in beams and columns (Figure 13). In some cases, the cracking around the panel edges is significant and could lead to out-of-plane failures of the wall panel in future shaking.

Figure 12 – Cracking around infill panel perimeter at interface with concrete frame at interior (left) and exterior (right)

Figure 13 – Column-to-beam joint damage

Figure 14 – Significant panel edge cracking

Some pounding damage was observed due to the interaction of the buildings at the seismic joints (Figure 15). The pounding appeared to cause only localized damage at the building roof and slab.

Shear cracking of several wall panels was also observed (Figure 16). This implies that, despite the foam interface between the masonry wall panels and frame, the panels were engaged to resist lateral forces during the earthquake.

Figure 15 – Evidence of pounding

Figure 16 – Shear cracking of infill

Potential Seismic Deficiencies

- Non-ductile concrete frame - Due to the age of the concrete moment frame structure, it is likely that ductile frame detailing specified in more recent building codes is not present. In the absence of the wall panels to help resist lateral loads, the frame would likely have significant damage and drift – potentially failure.

- Unconfined wall panels – With the joint material separating the infill from the frame, the panel is largely disconnected and unconfined. Unconfined wall panels can more easily suffer out-of-plane failures.

- In adequate seismic joint – The small joint between buildings could result in pounding damage in future earthquakes. However, given that the floor and roof slabs align, significant damage due to this pounding, such as a collapse, may be less likely.

Potential Retrofit Strategies (Concrete frame buildings)

- Replace infills strategically to create solid shear wall panels.
- Connect or confine all masonry infills.
- Provide reinforced concrete overlays to the shear walls as needed for increased strength.
- Effectively repair damaged beams or columns.

3.3 INMO INSTITUTO NACIONAL MIXTO DE OCCIDENTE

Location: 9na Calle y 11 ave. Zona 1, San Marcos
Site visit host: Local authority representative
Number of students: Unknown
Building types and status: (1) New (post-earthquake) confined masonry 2-story, undamaged, occupied; (1) 3-story confined masonry - damaged, partially repaired, partially occupied; several 1-story unreinforced or partially confined – damaged, unoccupied

General Description
There are three main structure types at the INMO school. The school site is gently sloped, with about a one-story height difference from one side of the campus to the other. There are one-story unreinforced or partially confined older buildings (Figure 16), a three-story confined masonry structure (Figure 17) and a new two-story confined masonry building (Figure 18). The older portion of the build also houses a two-story tall auditorium space (Figure 19). The one-story structures typically have light-weight roofs. The two and three story structures have concrete slab roofs.

Figure 16 – Front of INMO – one story partially confined buildings

Figure 17 – Three-story confined masonry building

Figure 18 – New two-story confined masonry building

Figure 19 – Auditorium space

Damage Observed

The two-story building was constructed after the earthquake and therefore had no damage. The one-story structures had some in-plane (Figure 20) cracking and out-of-plane failures (Figure 21) of the unreinforced masonry walls. The three-story structure was more heavily damaged and only partially repaired. There was evidence of wall failures in shear (Figure 22), short column failures (Figure 23) (which had been repaired by adding a new column next to the failed column (Figure 24)), and residual out-of-plane wall movement (Figure 25).

Figure 20 – In-place cracking of URM

Figure 21 – Unreinforced masonry wall out-of-plane failure

Figure 22 – In-plane shear failure (masonry and column)

Figure 23 – Short column shear failure damage

Figure 24 – Short column repairs (double columns installed)

Figure 25 – Out-of-plane wall movement and separation from frame

Potential Seismic Deficiencies

- Lack of ring beam at light weight roofs (URM buildings) – Without an upper ring beam to help the wall span out-of-plane between cross walls, URM walls remain susceptible to out-of-plane failures.

- Insufficient connection at wall intersection (URM buildings) – The out-of-plane wall demands can cause cracking at wall intersection that are not sufficiently tied together.

- Insufficient wall strength or number of walls – Due to the large cross wall spacing, the types of wall construction, and the observed damages, it is likely that the current wall configuration and strength is inadequate to provide the required lateral strength to the buildings.

- Excessive distance between cross walls – This can lead to overstressing the parallel cross walls that do exist as well as lead to premature out-of-plane failures in perpendicular walls where there are light-weight roofs.

- Excessive height-to-thickness ratios – The auditorium walls, the front cantilevered perimeter wall and the unreinforced/unconfined masonry walls have excessive height-to–thickness ratios, which mean they are slender and susceptible to out-of-plane failure or collapse.

- Lack of shear walls in longitudinal direction – The two-story and three-story buildings had windows comprising the majority of the longitudinal wall elevations at all levels. This reduces the lateral strength and stiffness of the building in the longitudinal direction.

- Short column conditions – The short columns at the windows along the longitudinal elevations are prone to shear failure in an earthquake, unless a stiffer lateral load path – such as a shear wall is provided – in series.

- Lack of seismic joint – The new two-sotry building wall built flush against the existing three-story building. The slabs are nearly aligned, but not completely and pounding damage could be anticipated in an earthquake.

- Cantilevered upper level walls (vertical discontinuity) – The third level of the three-story building is cantilevered out above the second level. This means that the third floor walls along that line do not have vertical continuity or a rigid load path for vertical resistance to overturning in an earthquake. Excessive cracking these third floor walls could be expected as the support below flexes when the wall has increase bearing and overturning loads in an earthquake. It also reduces the stiffness and capacity of the lateral system at the third level and generates unnecessary loading on the slab and framing between the two levels.

Potential Retrofit Strategies

- Demolish leaning walls

- Replace or repair damaged walls and strengthen as needed

- Infill some windows along the longitudinal elevations to create solid shear wall panels

- Install a ring beam sufficient to brace the walls out-of-plane at the light weight roofs

- Thicken slender walls with a reinforced concrete overlay (or rebuild with wider blocks)

- Demolish cantilevered third floor walls and rebuild aligned with supporting walls below

- Tie intersecting walls of URM buildings together with added vertical confining ties

- Increase the ductility of URM walls by adding reinforced concrete elements at the doors and windows.

3.4 ESCUELA OFICIAL DE VARONES NO. 3 "DELFINO AGUILAR"

Location: 5a calle, Zona 4, San Marcos
Site visit host: Local authority representative
Number of students: Unknown
Building types and status: 1-story masonry, partially confined – damaged, partially repaired, occupied

General Description
The building is single-story and U-shaped around a central courtyard (Figure 26 and 27). There is a taller portion at the front of the building (Figure 28). The building has a concrete roof at the entrance, and light-weight roof at the classroom wings. The walls appeared to be partially confined brick masonry walls. The site is essentially flat.

Figure 26 – Front of school


Figure 27 – Side of school along classroom wing (from exterior)

Figure 28 – Taller portion at entrance

Damages Observed

There was evidence of prior cracking where the roof met the exterior wall (Figure 29), cracking at columns along the window sill level (Figure 30) – particularly on the courtyard side where there were few walls and mostly windows, cracking at the top of walls (Figure 31), and some shear cracking in walls (Figure 32).

Figure 29 – Evidence of horizontal cracking at wall-roof intersection

Figure 30 – Cracking at column base at window sill

Figure 31 – Cracking at the top of walls (where wall and ceiling pulled apart)

Figure 32 – Shear cracking in wall panels

Potential Seismic Deficiencies

- Lack of ring beam at light weight roofs (URM buildings) – Without an upper ring beam to help the wall span out-of-plane between cross walls, URM walls remain susceptible to out-of-plane failures.

- Insufficient wall strength or number of walls – Due to the large cross wall spacing, the types of wall construction, and the observed damages, it is likely that the current wall configuration and strength is inadequate to provide the required lateral strength to the buildings.

- Excessive distance between cross walls – This can lead to overstressing the parallel cross walls that do exist as well as lead to premature out-of-plane failures in perpendicular walls where there are light-weight roofs.

- Lack of shear walls in longitudinal direction at courtyard elevations – At the courtyard facing elevations, the longitudinal walls had very few solid wall panels and mostly windows. This reduces the lateral strength and stiffness of the building in the longitudinal direction.

- Configuration – The building is U-shaped and could experience increased damage at the corners and wing intersections.

Potential Retrofit Strategies

- Replace or repair damaged walls and strengthen as needed
- Infill some windows along the courtyard longitudinal elevations to create solid shear wall panels
- Install a ring beam sufficient to brace the walls out-of-plane at the light weight roofs
- Tie intersecting walls of URM buildings together with added vertical confining ties where confining elements are missing

3.5 ESCUELA OFICIAL URBANA MANUEL ENECON LOPEZ (exterior view)

Location: 1 calle 12 - 25 Zona3, Quetzaltenango
Site visit host: Local authority representative
Number of students: 192
Building types and status: 2-story confined masonry - repaired, occupied

General Description

This is a two-story confined masonry building (Figure 33). Access inside the school yard was not permitted during the visit and so observations were made from the exterior. The building has a lightweight roof. The site is sloping.

Figure 33 – Front elevation

Potential Seismic Deficiencies:

- Lack of longitudinal walls – The longitudinal walls were only half-height to permit windows at the upper half of the walls. This reduces the lateral strength and stiffness of the building in the longitudinal direction.

- Short columns - The short columns at the windows along the longitudinal elevations are prone to shear failure in an earthquake, unless a stiffer lateral load path – such as a shear wall is provided – in series

- Torsion – Depending on the configuration of the lower half of the building, it is possible that the sloping site could cause stiffness irregularities, leading to torsion of the structure.

Potential Retrofit Strategies

- Strengthen existing walls as needed.
- Infill some windows along the longitudinal elevations to create solid shear wall panels.
- Stiffen and strengthen the downhill lateral system elements to reduce effects of torsion.

3.6 ESCUELA OFICIAL RURAL MIXTA CANTON CHOQUI ALTO

Location: 7 avenida 10 - 45 Zona 5, Quetzaltenango
Site visit host: Local authority representative
Number of students: Unknown
Building types and status: 1-story confined masonry – damaged, partially repaired, occupied

General Description

This school had multiple one-story confined masonry buildings with light weight roofs (Figure 34). The masonry gable end walls were low-rise and typically had confining elements (Figure 35). The site was flat. The building was only observable from the exterior during the visit.

Figure 34 – Low-rise confined masonry school buildings.

Figure 35 – Confined masonry gable end wall

Damages Observed

Portions of the cantilevered perimeter wall had collapsed and were replaced by metal sheeting (Figure 36). One building had suffered damage to the windows. The school infilled these windows with masonry in order to close the damaged windows and strengthen the building (Figure 37).

Figure 36 – Temporary perimeter wall

Figure 37 – Masonry infill at damaged classroom windows

Potential Seismic Deficiencies

- Lack of longitudinal walls - The longitudinal walls facing the interior of the site were composed of mostly windows and not wall panels (Figure 38). This reduces the lateral strength and stiffness of the building in the longitudinal direction.

- Excessive distance between cross walls – This can lead to overstressing the parallel cross walls that do exist as well as lead to premature out-of-plane failures in perpendicular walls where there are light-weight roofs.

Figure 38 – Interior longitudinal wall elevation

Potential Retrofit Strategies

- Strengthen walls as needed
- Infill some windows along the longitudinal elevations to create solid shear wall panels
- Dry pack grout at perimeter of recently infilled windows to ensure confinement of masonry panels.
- Add bracing to top of wall at diaphragm level to decrease out-of-plane wall deflections