EARTHQUAKE HAZARD CENTRE
NEWSLETTER

Vol.16 No.4 APRIL 2013 ISSN:1174-3646

Contents

Editorial

In the last Editorial which considered different types of earthquake shock waves, namely literal and figurative waves, I noted that it had been two years since most of the unreinforced masonry buildings in Christchurch had been destroyed. The Canterbury earthquakes were a stark reminder of the vulnerability of unreinforced masonry construction during an earthquake. However for large areas of the world with no or little seismicity unreinforced masonry is very commonly used.

At present I'm staying in the UK and here, even for new buildings, like houses, unreinforced masonry is by far the most prevalent material. Just along the lane from where I'm staying a large house addition and a brand new house are underway. All the walls including large gable walls are constructed with solid concrete block masonry. There is an outer wall, of brick, tied to the inner wall and with some type of insulation in the cavity. Presumably the local building codes prevent thin walls spanning too far horizontally and vertically. After all, wind face-loads must be resisted safely. But for we who design in the expectation of a damaging earthquake, this type of construction seems exceeding vulnerable. The thought of all these walls, in fact every wall, without any reinforcement is almost unbelievable.

Those of us living in seismically active regions are unfortunate in having to work so hard to incorporate masonry into a new building. The first assumption we make is that as far as an earthquake is concerned, an unreinforced masonry wall has no significant strength against face-loads, and not only that, but that same wall can also be a hazard to structure like a reinforced concrete frame.

Therefore we adopt a number of different strategies to use this ancient, economic and versatile material in our buildings. To prevent collapse under face-loads we tie walls back to structural walls behind, or to vertical studs, be they wooden or metal. This structure, under face-loads will transfer half of the wall inertia forces to the foundations and half to a roof or ceiling diaphragm. In some countries where confined masonry is used, the masonry walls are strengthened by small horizontal and vertical reinforced concrete members that are cast after the masonry units are laid and are located within the thickness of the walls. By being cast against the masonry units the RC members 'confine' the masonry under face loads. Confined masonry walls are also able to resist in-plane forces, or in other words, act as bracing panels for buildings.

The second problem we have is the contrast between the rigidity of a masonry wall and the framing around or adjacent to it. Structural framing members like beams and columns will flex during an earthquake and so we often provide separation gaps between walls and columns to allow this movement to occur without the walls causing structural damage. Once gaps have been formed then they have to be covered by flashings to exclude wind, rain and possibly fire. It is all quite complicated to do it correctly, and it's all due to the fact that, unlike my current neighbours, we live near the edges of tectonic plates!

Virtual Site Visit No. 32: Incorporating a facade into a new building

Owners of unreinforced masonry buildings in Wellington, New Zealand, are being given two choices. They can either bring their old building up to modern seismic safety standards or they can demolish it and rebuild. Where the façade of the existing building is of historic importance sometimes it is retained and incorporated into the new construction. This is the situation we encounter on this site visit.

Before demotion of the main body of the building is complete, the façade is given temporary support. As shown in Fig. 1, on this site five steel frames protect it and ensure its stability during the construction period. Once demolition is complete, the foundations for the new construction begins and after piles are placed down to firm founding material (about 15 m deep here) and foundation beams poured, work begins on new shear walls (Fig. 2). The vertical and horizontal reinforcement ensure the walls can resist bending moments and shear forces. In this building, shear walls resist lateral loads in both orthogonal directions in plan. This is a sensible decision given that the walls are supporting the brittle masonry façade. If stiff structure like walls didn't limit horizontal deflections in an earthquake the façade would suffer considerable damage.

Fig. 3 shows some of the walls, but there are others on two boundary lines that provide additional strength and as well as necessary torsional resistance. In Fig. 3 we can see the brick façade beyond the shear walls. It has been given extra face-load support by vertical steel members fixed behind it, and then each suspended floor will also be firmly attached to it to prevent damage under face-loading. We also observe new steel posts and beams. These members comprise the gravity-only structure to support the new floors, all of which will have their horizontal loads resisted by the shear walls.

Fig. 1 Unreinforced masonry facade with its temporary restraining structure.

Fig. 2 Workers fix reinforcing steel for the new RC shear walls.

Fig. 3 New shear walls in each direction with the old facade behind.

LEARNING FROM EARTHQUAKES

A summary of "Reconstructing Schools in Post-Earthquake Haiti ",

by D.J. Carson and E. Oldershaw, S. Copp, and K. Cryer, from Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, 2012.

Introduction

On January 12, 2010, a Magnitude 7.0 earthquake destroyed the capital of Haiti, Port au Prince, and large parts of the built environment across the country. It left around 1.5 million people homeless, destroying over 100,000 homes and leaving another 200,000 severely damaged. It also destroyed or damaged around 4,000 schools, including 80% of schools in Port-au-Prince and 60% of schools in a large area in the southwest of the country.

Project Overview

Following the earthquake, four Canadian Structural Engineering Consulting firms - Blackwell Bowick, Halsall Associates, Quinn Dressell, and Read Jones Christoffersen - collaborated in a pro-bono project to assist in rebuilding schools in Haiti. The four companies committed to having at least one field engineer present in Haiti for a total term of 18 months, with a team of designers backing up the field presence. Together the joint venture firms have made significant donations of time and expertise to design and build robust, sustainable school structures and to transfer important skills and expertise to local professionals.

The reconstruction of the schools was administered through Finn Church Aid (FCA) who undertook a long-term mandate to construct approximately 50 permanent schools over a 5 year period. FCA was responsible for the management of the project, securing the funding and engaging the technical expertise for all project activities. The owner of the school sites worked on to-date is the Bureau Anglican d'Education en Haiti (BAEH) of the Episcopal Church, who has worked with FCA as their local partner.

The project's primary goal was to use durable, locally sourced materials to build permanent schools rather than temporary or transitional ones. Each of the companies involved pledged to contribute to an adaptable design for school buildings, to oversee the construction of the prototype schools and to transfer skills to Haitian engineers that would equip them to take over the design and review of future schools.

Following initial reconnaissance it became clear that the extensive earthquake damage in the Zone extending from Port au Prince west to Leogane and south to Jacmel, presented communities and terrain which ranged from reasonably flat and accessible by road to extremely rugged terrain only accessible by foot. To respond to both of these conditions, the four firms designed two structural prototypes concepts for new schools. A heavyweight structure (Figs 4,6,7) incorporating reinforced concrete columns, beams, and shear walls with rubble masonry infill walls, was designed for areas accessible by road (e.g., St. Matthieu School in Leogane). Also, an alternative, lightweight structure was designed (Fig. 5) for rural areas where there is no road access and building materials must be transported on foot. The lightweight structure relies on timber stud wall construction with plywood shear walls (e.g., St. Joseph School).

Fig. 4 St. Matthieu School Concrete Shear wall Prototype.

Materials for construction were selected based on local availability with a goal of illustrating how conventional readily available local materials can be used to construct robust, durable and safe structures. To this end the materials selected as load bearing structural elements include timber, and reinforced concrete, with masonry only used for non-loadbearing elements.

Throughout the project, efforts were made to make all designs as simple as possible for local contractors to follow. To assure the success of the project, an experienced Canadian field engineer was sent to Haiti, whose role was not only to oversee the structural work but also to help coordinate the many different elements of the project. The field engineer assisted with project layout, demolition, scheduling, safety issues, quantity calculations, building envelope details, civil works, plumbing, electrical work, quality control, training of the site staff and paperwork issues.

To ensure that the schools were built properly, site supervisors and tradespeople had to be trained in good practices. Language barriers and illiteracy were both issues and the local workers tended to build more or less what the drawings illustrated. The structural drawings had to be adapted so they could be easily understood, for example, if the designs called for 33 nails in a connection, all 33 nails had to be illustrated in the correct locations on the drawing to avoid construction errors. The lesson learned is that success depends on keeping the design simple, clearly communicating the requirements, then making sure those responsible for the construction at all levels understand the need and expectation, that the actual work follows the design details.

Protoype Concepts

Construction standards in Haiti are typically low and buildings are unable to withstand large seismic forces. Haitian buildings traditionally have reinforced concrete roof slabs and poorly defined lateral-load-resisting systems. The lateral load resisting systems are often based on unreinforced masonry or confined masonry, recent earthquake experience proved that this does not stand up to the high seismic levels prevalent in the area. For the new schools, the types of construction were carefully chosen to fulfil the requirements of the NBCC and enable the team to use locally available construction materials. For

Fig. 5 St. Joseph School timber Frame Prototype.

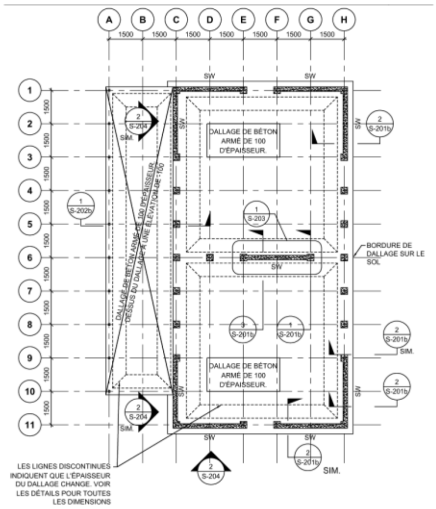


Fig. 6 Typical 2 classroom module.

both Prototype concepts the designs included timber truss roof structures with well-connected plywood roof diaphragms that attract lower seismic loads because of their small masses and have demonstrated high resistance to lateral loads. In addition, well defined, uniformly distributed systems of shear walls made of either timber or reinforced concrete were used to support the roofs.

Masonry is a widely used material for construction in Haiti. As a result stone rubble is in abundant supply from buildings destroyed by the earthquake. By using rubble masonry in a nonloadbearing role, and ensuring that the masonry is well anchored to the surrounding structure, a sound structural example that makes good use of the skills and materials readily available was developed.

Where timber construction was employed on the projects a borate solution treatment was applied to the timber on site rather than using pressure treated lumber. This simple precaution allowed all of the untreated scrap lumber to be used by the communities as fuel for cooking, as is the common practice in Haiti. This avoided having people exposed to potentially toxic fumes from burning pressure treated lumber scraps.

Conclusions

In a country where 50% of the population is illiterate, the new schools give numerous children access to an education that they would not otherwise have. By contributing to increased child literacy levels, the hope is to enable Haitian people to gain the skills and education that will be necessary to rebuild not just their homes and communities, but an entire economy.

Many Haitians lost their livelihoods after the earthquake. The school-building projects provide badly needed employment for local builders, and many of the labourers which were hired for the school construction are parents of the children that will be attending the schools. As part of the project, the team was able to help local labourers learn valuable new skills ranging from properly mixing concrete to carpentry and masonry work as well as allowing members of the community to feel a pride of ownership in the project by being involved in the construction.

Wherever possible, construction materials were sourced and recycled locally. For example, in the heavyweight prototype school, rubble masonry infill walls were designed, using recycled rubble from buildings destroyed by the earthquake.

This project has had a tremendous positive social and economic impact in Haiti and beyond. It has given Haitian children and young people safe and comfortable buildings in which to learn and has provided work and income to Haitian builders. It has also established connections between Haitian and Canadian engineers, offering a model of cooperation to a domestic engineering industry that typically focuses on competition rather than collaboration among companies.

Throughout the project, Canadian engineers liaised not just with local construction professionals but also with church leaders, school principals, teachers and many other members of the local community to ensure that their needs were met. In collaboration with the partnering firms, two schools were completed during the first year, opening their doors to almost 600 local children in time for the beginning of the Haitian school year. In addition three schools were taken into construction, with three more out for tender and three other schools prepared for tender.

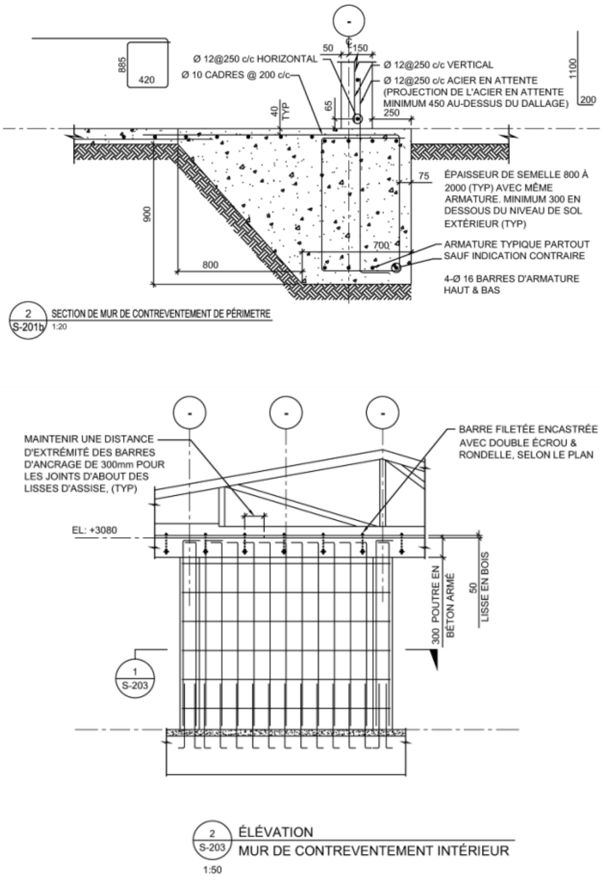


Fig. 7 Typical Concrete Shear wall Details.

A suite of classroom modules for each construction prototype has been prepared which can be easily adapted to future sites and soil conditions.

The Haiti schools project demonstrates how, through creativity and innovation, buildings of quality and excellence can be produced even in the aftermath of one of the world's largest natural disasters and in the absence of any locally established, adopted or enforced building code.

The team of Canadian Engineers which collaborated in the project conclude that the experience of participating in a small grass root Pro Bono volunteer effort can create real benefit to the community in need. A significant additional benefit appreciated by the engineering team was the opportunity for engineers from different firms to work cooperatively without the need for competition to achieve a collective goal.

A Summary of "Performance of masonry buildings during the 2011 Lorca earthquake" by L. Hermanns from Proceedings of the 15th World Conference of Earthquake Engineering, Lisbon, 2012.

Summary

On Wednesday 11th May 2011 at 6:47 pm (local time) a magnitude 5.1 M_w earthquake occurred 6 km northeast of Lorca with a depth of around 2 km. As a consequence of the shallow depth and the small epicentral distance, important damage was produced in several masonry constructions and even led to the collapse of some of them. Pieces of the facades of several buildings fell down onto the sidewalk, being one of the reasons for the killing of a total of 9 people.

The objective of this paper is to describe and analyze the failure patterns observed in unreinforced masonry buildings ranging from 3 to 8 floors in height. First, a brief description of the local building practices of masonry buildings is given. Then, the most important failure types of masonry buildings are described and discussed. After that, a more detailed analysis of one particular building is presented.

Introduction

Reinforced concrete frame buildings with masonry infill walls are very common in Spain. Many of these buildings were damaged by the earthquake however, in terms of catastrophic failures the situation did not reach dramatic proportions. Actually only one building collapsed; a recently built apartment house. Only two hours before the main event occurred, a smaller earthquake was registered. This smaller event already caused some damage to several buildings and was the reason for the evacuation of the building that collapsed due to the damage suffered during the main event.

The situation on the streets was quite similar throughout the whole town. Fig. 8 displays the situation of one of the streets in Lorca immediately after the main event took place.

Many pieces of the facades that fell down during the earthquake injured a lot of persons. In some occasions façade infill panels located at upper floors and roof parapets collapsed and fell onto the ground. Two different failure mechanisms are thought to be responsible for their collapse.

Fig. 8 Building with a almost completely collapsed parapet wall.

In the case of roof parapets, chimneys and to a minor extent infill panels at upper floors the failure was caused by inertia forces acting out-of-plane. It is well known that the resistance of masonry walls to out-of-plane moments is much lower than that of R.C. frames. As a consequence the interaction between the frames and the infill panels is very limited in this particular loading scenario as the failure of the infill panel changes the structural properties at a very low load level. Regarding unreinforced roof parapet walls some codes point out the significant falling hazard related to this type of architectural components. Figure 8 shows one of the parapets that partially collapsed confirming thereby the importance of studying the seismic behaviour of non-structural components. The structure of this particular building did not suffer significant damage whereas the roof parapet almost completely collapsed.

This type of incoherence in terms of the seismic behaviour of different components of the same building should be avoided. It is important to note that the acceleration at roof level may be significantly higher than that at ground level due to the dynamic properties of the building. In addition, the bending moment capacity at the contact surface at roof level is usually quite small if the parapet wall is not adequately anchored. Not only parapet walls failed at this load level but also chimneys on flat roofs.

On lower floors the failure of masonry infill panels was caused by excessive in plane loads, displacements of the frame structure (see Fig. 9) and in some cases by pounding of adjacent buildings. The interstory height at ground floor level is usually higher than that of the upper floors as the ground floors are usually occupied by shops. In these cases both the stiffness of the framing structure and that of the masonry infill are comparable and the resistance of the infill panels is significant permitting thereby important interactions like a force transfer from the slightly cracked masonry wall to the surrounding frame structure. Although in some cases a combination of the two different failure mechanisms described above was observed, in general, the first one was more often observed on upper floors and the second one on lower floors.

Failure Patterns of Non-Structural Masonry Wall

After the earthquake a damage assessment was performed revealing that most of the damage may be classified as well known failure modes due to the interaction between the frame structure and interior partitions or façade elements. A distinction of these failure modes may be drawn depending on whether the initial combination of the lateral resistive elements is responsible or whether the progressive failure of some of them and the accompanying change of the stiffness distribution leads to an excessive seismic demand. The following 5 points belonging to the first group have been observed in Lorca

—Some buildings didn't seem to have effective mechanisms to resist lateral loads. However, most of them did not suffer excessive damage. In these cases the stiffness of the masonry infill panels add to the one of the frame structure and the infill panels resisted quite well. The damage distribution was similar to the one observed in buildings with an effective lateral load resistance mechanism.

—Asymmetrical horizontal stiffness distribution leading to torsion moments. This was quite often the case in corner buildings of apartment blocks. The only building that collapsed during the earthquake falls into this category. Other corner buildings with asymmetrical horizontal stiffness distribution suffered substantial damage.

—Soft storey mechanisms due to infill panels with lower stiffness at the ground floor level and panels with higher stiffness at upper floors. In many cases the interstory height at ground floor level was significantly higher than that of the upper floors favouring thereby the generation of a Soft storey mechanism.

—Masonry infilling effect on frame columns. The horizontal displacements of the frame columns are restricted due to the presence of the masonry wall. The reduced height of the column increases the forces the column experiences during a seismic event.

—Shear force concentration in combined systems consisting of R.C. columns and masonry shear walls. In

Fig. 9 Damaged masonry infill walls at ground floor.

order to estimate realistic shear forces during the design phase it is crucial to take the stiffness of the masonry wall into account however, quite often infill panels are not considered in the structural building model that is used for the seismic response analysis. It is quite common that only one infilled bay exists at ground level. In this case the infill is usually part of the elevator core walls.

A progressive failure of the infill panels or the frame columns and the accompanying change of the stiffness distribution is thought to be responsible for the following 2 failure patterns observed in Lorca.

— Formation of soft storey mechanisms due to the progressive degradation of the infill panels located at ground floor levels.

— Column failure due to interaction forces between the masonry walls and the RC columns. The adjacent frame columns are usually not designed considering different failure modes of the masonry walls and the resulting force redistribution.

Interaction of Structure and Infill Panel

According to (WHE 2006) the performance of buildings with masonry infill in the frame panels in past earthquakes has revealed that the presence of masonry infill walls is typically detrimental for the seismic performance of the building. The numerical simulation of whole buildings in their elastic and post-elastic ranges up to failure is even today quite challenging. Usually macro models are used when whole structures are analyzed whereas micro models are only employed when laboratory tests of structural elements are simulated. When using macro models it should be remembered that these models are generally unable to capture some of the failure modes described in the following.

Failure of the beam-column junction

Joints are usually critical points in structures and many efforts have been put into the study of its behaviour. The importance of an adequate design is widely recognized however, quality control during construction is also very important. Construction joints in columns are usually located at the undersides of the slabs and beams.

Shear failure of the infill panel

This type of failure is particularly dangerous because of the damage that is caused to the compression zone of the infill panel i.e. the load carrying strut in an equivalent strut model. If the failure results in the formation of two struts, indicated in Fig. 10 b and Fig. 11, important forces act on the column sections almost at mid-floor height. The formation of two struts may be favoured by the existence of conduits, openings or other discontinuities in the infill panel.

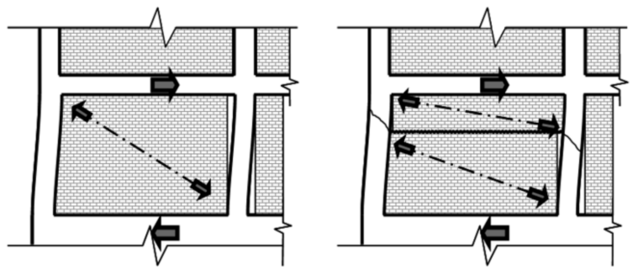
Conclusions

The damages caused by the Lorca earthquake to structures that were built during the last 20 years indicate that lessons that should have been learned from previous seismic events have been, at least partially, ignored or misinterpreted. If R.C. frames are built with infill walls but their effect is not accounted for during design calculations and the structural analysis, the consequences may be catastrophic.

The differences in stiffness and ductility between the structural model (without infill) and the built structure can be very large. As masonry infill walls may significantly affect the way in which the building responds to the seismic event it should not be surprising that some buildings collapse although the magnitude of the earthquake is not very high. In this case the seismic loads that are used to analyze the seismic response of the structure may vary significantly from what the building will be subjected to. As a consequence of using erroneous design loads the members' ductility and resistance may result insufficient even for moderate earthquakes. This raises the question whether the seismic load case has been adequately studied.

If the masonry infill panels are not included in the structural model that is used to study the seismic behaviour of the building, the non-structural infill walls should be designed and built with gaps to accommodate frame drifts; this solution is also known as isolated infill.

The falling hazard of damaged parapet walls is well known and addressed in several guidelines like (FEMA 2011). The importance of non-structural elements in the context of a seismic analysis should be evaluated taking into account their damage potential, not their cost.



(a) (b)

Fig. 10 Force transmission before (Fig. 10 a) and after (Fig. 10 b) shear failure of the infill panel.

(a) (b)

Fig. 11 Example of cracks crossing a column at mid-floor height. Building (Fig. 11 a) Detail (Fig. 11 b)

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

The Centre is a non-profit organisation based at the School of Architecture, Victoria University of Wellington, New Zealand.

Director (honorary) and Editor: Andrew Charleson, ME.(Civil)(Dist), MIPENZ
Research Assistant: Kate Bevin (BAS)

Mail: Earthquake Hazard Centre, School of Architecture, PO Box 600, Wellington, New Zealand.
Location: 139 Vivian Street, Wellington.
Phone +64-4-463 6200 Fax +64-4-463 6204
E-mail: andrew.charleson@vuw.ac.nz

The Earthquake Hazard Centre Webpage is at :
http://www.vuw.ac.nz/architecture/research/ehc/