EARTHQUAKE HAZARD CENTRE
NEWSLETTER

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Contents

Editorial: Collaboration between architects and structural engineers

Currently I'm on a working group that is developing a Practice Note for New Zealand architects and engineers to raise the quality of their collaboration. The need for this document has arisen from building damage during the 2010 and 2011 Canterbury earthquakes. In particular, the Royal Commission that investigated and reported on the damage made two recommendations regarding collaboration. First, it recommended that architects work with structural engineers at the concept design stage of a project, and secondly, that the professional bodies representing architects and engineers pro-actively encourage better collaboration between the two professions. These recommendations arose after discovering that a number of buildings damaged in the quakes were not well-configured seismically. It was found that there were some serious torsional eccentricities as well as insufficient strength for some of the force paths within structures.

The need to improve collaboration between architects and engineers is an international problem. Too often architects go well beyond the concept design stage before engaging a structural engineer, and by that time the structural layout might be quite fixed. Given that the architect may be unwilling to change the column layout or orientation, the engineer tries to achieve a sound structural system for seismic performance, but invariably compromises are made that result in structures that will not perform nearly as well as they could. Also it is common for the final structural system to be more expensive than one jointly developed by architect and engineer collaboratively. The ideal is for engineers to advise architects from day one of the project. Then, with good collaboration both professionals can end up with a structure that will perform well in a damaging earthquake. For example, any torsional eccentricities will be minor, and there will be an absence of critical structural weaknesses such as soft stories or short columns etc.

Here are five tips for improving collaboration -

For engineers:
- Appreciate that architectural design involves the synthesis of a very wide range of different criteria, is by nature, iterative, and therefore is different from engineering design.
- Contribute as constructively as possible to the design team in the expectation that some earlier solutions will need reworking.
- Look beyond conventional solutions for innovation that could better the project.
- Understand the desired architectural concepts and qualities before suggesting solutions.
- When the lead consultant on a seismic retrofitting project, recommend the client engages an architect.

For architects:
- Initiate collaboration as early as possible by engaging a structural engineer at pre-design/concept design stage for the best project outcome.
- Match an engineer's expertise and experience with the complexity of the project.
- When leading a design team, cultivate an open and trusting culture to facilitate knowledge sharing, and encourage a 'best for the project' consensus approach.
- Facilitate communication between design team members so that all are satisfied with and take responsibility for the solutions at each design stage of the project.
- Increase your understanding of structural and non-structural seismic design issues.

Virtual Site Visit No. 34; Low- to medium-rise steel-framed apartment building, Wellington

The primary structure of this apartment building consists of structural steel framing. As can be seen from Figure 1, a series of equally-spaced single-bay eccentrically braced frames resist both gravity and transverse seismic and wind loads. In a rather unusual combination of precast concrete and steel, floor gravity loads are resisted by pre-cast concrete ribs that span longitudinally between the steel frames (Figure 2). The eccentricity between the diagonal bracing members is clearly visible, and it is this section of steel that will be severely distorted during the design earthquake or greater. Provided both the steel material and the detailing of this region is of high quality, this is where the earthquake energy will be dissipated to enable the frames to suffer overload without collapse – ie behave in a ductile manner.

In the longitudinal direction a completely different structural system is used – two perimeter moment frames along the sides of the building. A column of one of these frames can be seen in Figure 2, just to the left of the eccentrically-braced frame column. The moment frame column, although very close to the transverse frame column acts independently. The moment frames have their own columns and moment resisting beams.

In Figure 3 we see a typical rigid beam-column joint. The shear forces from the beam web are resisted by a total of six bolts through a web plate, welded to the column. Bending moments are transferred to the column via welded flange plates that connect to each beam flange also with bolts on each side of the web.

But this rigid joint is very different from typical joints. The reason can be seen by looking at how the holes at the bottom of the plates welded to the column are prepared. They are slotted rather than round! This special detailing is to allow ductile behavior in the frame without damage occurring.

The idea is that the bottom bolts which are high strength friction grip bolts are highly tensioned so that the joint is rigid for loads up to code loads. Then, in an overload situation the bolts and plates will slip. At the same time energy will be dissipated by friction between sliding plates and damage to the main structural elements will be avoided. This is an example of 'damage-avoidance design'. As you can imagine, it requires careful design and high-quality workmanship.

Fig. 1 A general view of the four-storey framing.

Fig. 2 The eccentrically braced frames resisting gravity and transverse loads.

Fig. 3 A beam-column rigid joint in the moment frame.

Fig. 4 Slotted holes in the bottom connections of the rigid joint for damage-avoidance design.

LEARNING FROM EARTHQUAKES

A Summary of "Lessons to be Learnt from Seismic Disasters in Algeria", by M. Chemrouk, from the Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon 2012.

Summary

Based on past seismic disasters that have struck the north of Algeria, this paper focuses on what should be gained and learnt from past earthquakes with the aim of improving, first the construction quality, and then, the intervention strategies in seismic hazard regions, with a particular emphasis on the disastrous effects of the 2003 Boumerdes –Algiers earthquake, considered as severe ground motion that has affected a population of about 4 million inhabitants, 2300 of whom have died, 11,500 have been injured and about 100,000 left homeless. As for the material damages, 150,000 homes have been affected, 10% of these homes have completely collapsed or needed to be demolished and 40% having serious structural damages. Indeed, in structural engineering there is always a risk that failures may occur and when they do occur, the causes and defects should be thoroughly examined and brought together in order to learn lessons and widen the knowledge to other engineers.

Concrete construction behaviour under seismic actions

In general, the degree of damage and technical disorders that occur in construction in a given earthquake depends on the conception and design of the structures, on the quality of the building materials and workmanship and finally on the maintenance throughout the service life. The type of soil on which constructions are built is also important in a sense that soft and inconsistent soils may amplify the seismic vibrations and hence aggravate collapses and destruction by comparison to rocky and hard soils. Indeed, during the 2003 Boumerdes-Algiers earthquake, an acceleration of 0.46g was recorded at Dar-El-Beida, an agglomeration distant 29 km from the epicentre, built mainly on soft and fertile agricultural flat land. In contrast, a smaller acceleration of 0.24g was recorded at the region of Kaddara1, eventhough relatively closer to the epicentre (20 km) than Dar-El-Beida, since the soil of this mountainous region is mainly a hard and rocky one.

In a seismically active region, a structural seismic design in accordance with the local seismic regulations should be carried out and implemented rigorously into practice. This should go inevitably through a well known design process starting with the architectural conception and then the structural analysis to check the safety of the structure adopted. This structural design should then be validated by an official control body. Then, the construction phase starts under the supervision of a site engineer with a tight collaboration from the design office (both the design engineer and the architect).

The necessary concrete mix should be carefully researched to obtain the targeted concrete material and the reinforcement detailing should be thoroughly examined by the control body before any concreting. In the construction process, full collaboration between the design office, the control body and the constructor is of a prime importance for a good quality construction that behaves as expected when confronted with a test of truth. Indeed, in many collapse cases examined, the construction process did not respect these steps and often the constructor did not have any site engineer; the lack of qualified workmanship with a tight supervision and better quality building materials appear to be the dominant technical causes of the earthquake disorders. In effect, it is worthless carrying out a sophisticated seismic design if it is not applied and fulfilled in practice at the construction stage with qualified engineers using a good quality building materials and good workmanship. The illustration in Figure 5 is a clear example of poor workmanship, leading

Fig. 5 Poor workmanship and bad quality concrete helped the seismic collapses.

to the neglect of transverse reinforcement at critical sections, and a bad quality building materials leading to concrete having very low strength; the deterioration of the concrete material and the corrosion of the reinforcement had started even before the earthquake.

Inadequate seismic design and conception of concrete structures in a highly seismic region may also lead to collapses. Typically, the presence of short columns at the base of some buildings or the short column behaviour created at the lower floors by in-fill masonry or window openings has caused distinctive failures repeatedly as in Figure 6.

When designing a building, the stiffness of a given floor should not be too low by comparison to that of the adjacent upper and lower floors. This also implies that, for existing buildings, floors should not be transformed into open spaces for any reasons, putting down all the partition walls. This uneven distribution of floor stiffness creates the principle of 'a stiffer body resting on a soft base'. The presence of soft floors in highly seismic regions, whether due to inadequate conception or to a subsequent transformation of the building, leads undoubtedly to catastrophic collapses as in Figure 7 and hence should not be allowed.

Soft soils and inconsistent soils such as filled material amplify the dynamic waves of an earthquake, resulting in collapses of the buildings. This is even more so for constructions at the edges of cliffs or hills made of these types of soil which may undergo ground sliding after the strike of an earthquake. Indeed, unstable hills and cliffs should always be avoided as building sites. In the same manner, river bed and valleys may be subjected to soil liquefaction after an earthquake whereby the soil looses its bearing capacity leading to sinking of the building, particularly the heavy concrete structures.

Seismic design that is not correctly implemented in practice on site was found as catastrophic as design that does not take into consideration seismic actions in regions that are seismically active. The 2003 Boumerdes-Algiers earthquake was a clear evidence of this fact.

A tight site control and a better workmanship to build correctly and implement the seismic design in practice is, indeed, what is needed to reduce the damaging effects of earthquakes on constructions and hence reduce the seismic risks. Figures 8 and 9 show two types of buildings,

Fig. 6 Failure due to short column behaviour.

Fig. 7 Failure due to soft floor effect.

Fig. 8 Example of a building that did not suffer from the earthquake, it was saved by adequate design/detailing and better workmanship.

beam-column concrete frames and shearwalls that have not suffered from any damage despite their location in the epicentral zone. In effect, 63% of the buildings located within the epicentral zone did not suffer from any serious damage at all despite the fact that they were originally designed to resist a lesser ground shaking event. What is certain is that the important number of concrete buildings which did not suffer from the major earthquake of Boumerdes-Algiers in 2003 is in itself prove that it is possible to resist a major seismic event that is not taken into consideration by the seismic regulations provided that the 'building rules' are fully respected and hence the quality of workmanship is adequate; such building rules can be summarized as follows:

- Carry out a site investigation to select an adequate building site and study the bearing soil.

- Follow-up tightly the local seismic guidelines for the architectural conception as well as the structural analysis and design.

- Use the targeted concrete material and ensure a better quality execution and workmanship under the supervision of a tight site control from both the design office and from an independent control body.

- Ensure a regular maintenance and repair work during the service life of the building.

In contrast to beam-column concrete framed buildings, concrete shearwall braced structures behaved well and showed no signs of distress and no collapses at all. This type of stiffer bracing presents the advantage of limiting greatly lateral deformations induced by seismic or other lateral forces. This reduced displacement due to increased lateral stiffness protects any existing concrete columns and non-structural elements such as masonry panels. Moreover, the use of shearwalls reduces the risk of construction defects and weaknesses often created at the beam-column joints and which was found to be the cause of most failures in beam-column concrete framed buildings.

Main Recommendations after the 1980 Chlef Earthquake

The devastating nature of this 7.3 magnitude earthquake, classified amongst the major earthquake disasters of the last century, had slashed away 70% of the built environment of the region and revealed the lack of preparedness of the country to cope with natural disasters of this kind. This earthquake was however the occasion for the Algerian authorities, and the population as a whole, to learn lessons from what has happened. An open-sky seismic training centre was there for everybody to learn about this natural hazard. The following points deserve to be recalled:

- Effort should be dedicated and sustained for training and information.

- Procedures should be set up to improve the quality of building materials.

- Procedures for granting agreements for intervention in the building sector should be tightened up and limited to professionals who have the necessary know-how.

- Control in the building sector should be tightened up (at design offices and at construction sites).

- Seismic hazards and micro-zoning studies should be generalised to the regions that are at risk.

- Installation of networks of equipment to record seismic characteristics when an earthquake strikes.

- Elaboration of a code for repair and strengthening of damaged constructions.

- Elaboration of a seismic code for the building sector.

- Creation of a research centre for para-seismic studies.

Apart from the last four recommendations which were implemented, the first five were not taken too seriously and non-qualified professionals still intervene in the building sector without any serious control, using concrete material that is not up to standards. Training and certification in the construction industry is very rare if not inexistent even after the 2003 earthquake.

Fig. 9 Buildings with combined shearwalls/beam-column framed structure under construction at the time of the 2003 earthquake – no sign of distress was shown.

A summary of "The seismic performance of unreinforced stone masonry buildings during the 2010-2011 Canterbury earthquake sequence ",

by I. Senaldi, G. Magenes, and J. M. Ingham from the Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon 2012.

Introduction

In the early morning of 4th September 2010 the region of Christchurch, New Zealand, was subjected to a magnitude Mw 7.1 event, located near Greendale, 40 km west of Christchurch at a depth of 10 km. This main event was followed by a considerable number of aftershocks, of magnitude Mw 3.0 or greater, including several damaging events. A severe aftershock occurred on 22nd February 2011, with a magnitude Mw 6.3 at a depth of 5 km and epicentre located 10 km south-east of Christchurch that produced accelerations greater than those measured during the 4th September 2010 earthquake and caused structural damage that affected all building types. The damage assessment inspections identified 90 unreinforced stone masonry buildings in Christchurch, including churches, many of which are included on the New Zealand Historic Places Trust register of heritage buildings.

Unreinforced Stone Masonry Buildings In Canterbury

Most of the stone masonry buildings in Christchurch tend to have similar characteristics both from an architectural and from a structural perspective. These similarities derive from the fact that many buildings were constructed in a relatively short period of time, between 1850 and 1930, and were designed by the same architects or architectural firms. The unreinforced stone masonry buildings in Christchurch have similar characteristics as regards the details of their construction. The vast majority of these structures, and in particular those constructed in the Gothic Revival style, are characterized by structural peripheral masonry walls that may be connected, depending on the size of the building, to an internal frame structure constituted of cast iron or steel columns and timber beams or to internal masonry walls that support flexible timber floor diaphragms and timber roof trusses. However, there are a few commercial buildings in the Christchurch Central Business District (CBD) that are characterized by slender stone masonry piers in the front façade with the other perimeter walls constructed of multiple leaves of clay brick. These buildings are typically two or three stories in height, with two storey buildings being most common, and may be either standalone or row type buildings. Several types of masonry wall cross-sections were identified during the damage assessment surveys. The most representative types present the following characteristics:

- three-leaf masonry walls, with dressed or undressed basalt or lava flow stone units on the outer leaves (wythes) while the internal core consists of stone rubble fill;

- three-leaf masonry walls, with the outer layers in Oamaru sandstone and with a poured concrete core;

- double-leaf walls, with the front façade layer being of dressed stone, either dressed basalt or bluestone blocks, or undressed lava flow units, and the back leaf constituted by one or two layers of clay bricks, usually with a common bond pattern, with the possible presence of a cavity or of poured concrete between the inner and outer leaves.

Damage induced by poor quality of construction materials

The quality of construction materials played a key role in the response of stone URM buildings. As previously described, one of the typical features of stone URM buildings in Christchurch is the different types of stone and mortar quality present in structures built with three-leaf walls. The use of soft limestone, such as Oamaru stone or the red tuff extracted in the Banks Peninsula, in conjunction with the use of low strength lime mortar, often led to poor earthquake response. Examples of such behaviour, frequently caused by hammering of the roofing system on the walls, include the Holy Trinity Church in Lyttelton, which is one of the oldest buildings in Canterbury, and St. Cuthberts Church as represented in Figure 10.

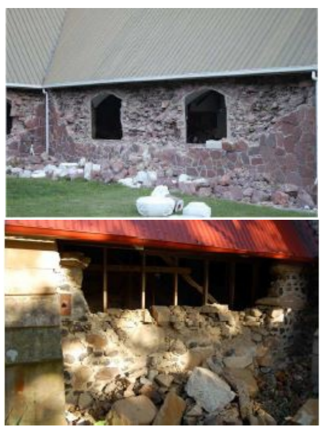

Fig. 10 Lyttelton Holy Trinity Church (above) and St. Cuthberts Church in Governor's Bay (below).

Damage due to geometric irregularities - damage that was attributable to plan irregularity was frequently observed, particularly for stone churches, due to interaction between adjacent structural elements at the intersections between walls. In most churches where the bell tower or low annexes are connected to the nave, damage developed at the intersection of the different structures.

Out-of-plane failure mechanisms - an example of out-of-plane failure is shown in Figure 11 relative to the main façade of the Anglican Cathedral (now partially collapsed after the 13 June 2011 earthquake and aftershocks).

In-plane response of walls - because the 22 February 2011 earthquake was predominant in the east-west direction, and because many of the buildings in the CBD were primarily oriented in the same direction, evidence of in-plane wall damage in the east-west running walls was reported in conjunction with overturning of façades oriented in the orthogonal direction. An example of a recurrent damage pattern is shown in Figure 12, where masonry piers of many of the stone masonry churches exhibited a shear type of response, evident by diagonal cracks that in some cases involved the buttresses. Also, a rocking behaviour was exhibited by the masonry piers.

Diaphragm and roof seismic response - a close inspection of buildings that suffered out-of-plane wall failures revealed that in many instances some anchors were present in the walls that failed, or that the inadequate securing of walls and diaphragms using wall-diaphragm anchors could not prevent portions of walls from overturning. In some cases anchors were either absent or were spaced too far apart to prevent bed joint shear failure of the masonry at the location of the anchorage. In those cases where anchoring had been seismically designed, or were sufficiently closely spaced to resist lateral loads, the overturning of gables and other portions of walls was prevented. Different examples could be given of a seismic response of a structure that was highly influenced by the effectiveness of wall-to-floor connections. For instance, Figure 13 shows the damage resulting from overturning of the gable of the main façade.

Seismic performance of retrofitted structures - one of the main objectives of the damage surveys of stone masonry structures was to investigate the response of structures that had been seismically retrofitted or strengthened at the time of the September 2010 earthquake. As previously illustrated one of the most common factors that contributes to the vulnerability of unreinforced masonry structure is the lack of connection between walls and diaphragms. However, a proper design of anchoring and the insertion of steel tie rods at floor and roof level helped reducing the likelihood of local failures due to out-of-plane collapse of walls and gables.

Different types of strengthening techniques were also applied to enhance the global response of buildings and to restrain the activation of possible local failure mechanisms. For instance, the use of steel moment frames as a retrofit strategy proved to be efficient in the case of the former Lawrie and Wilson Auctioneers Building. The insertion of vertical post-tensioned tendons in collaboration with buttresses and of horizontal tie rods in collaboration with floors improved the global response of another structure.

Fig. 11 Christchurch Anglican Cathedral: out-of-plane overturning of the front façade.

Fig. 12 Christchurch Anglican Cathedral: diagonal cracks in the south façade piers.

Fig. 13 Overturning of the front façade gable.

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