EARTHQUAKE HAZARD CENTRE NEWSLETTER

Vol.16 No.2 OCTOBER 2012 ISSN:1174-3646

Contents

Editorial: October 2012

I've recently returned from Lisbon where I attended the 15th World Conference on Earthquake Engineering. Some 3000 delegates from many countries ensured a very full if not overwhelming programme. As well as key note speakers several thousand papers were presented either as e-posters or in parallel sessions, making it very difficult to choose what sessions to attend. A huge amount of research had been undertaken since the previous conference four years ago and here many findings were disseminated. As well as theoretical academic and more practical research summaries, several sessions focused upon previous recent earthquakes. They are always a rich source of lessons to be learnt as we go into the future trying to improve our buildings' resilience.

An announcement as to when the proceedings of this conference will be publically available has yet to be made, but papers from all past World Conferences can be obtained from the International Association of Earthquake Engineering (IAEE) website free of charge. To have these proceedings so readily available is a tremendous resource for the world earthquake engineering community. It's possible to undertake a keyword search for each set of world conference papers separately.

There did not appear to be any hugely significant breakthroughs presented at the conference. Certainly there were many developments reported upon of interest and relevance to structural engineers and architects. Mostly relevant for more developed countries, there were a significant number of papers on seismic isolation, damage avoidance design and new design approaches like displacement-based design. These technologies are being implemented slowly until damaging earthquakes strike, such as has occurred in Christchurch, New Zealand, when interest in them and their uptake suddenly increases.

As far as materials useful for those practicing in developing countries, several sessions were a reminder of the resources available from the World Housing Encyclopedia. While various tutorials including those on reinforced concrete and adobe have been published, new information on stone masonry and confined masonry construction was introduced. Confined masonry, in contrast to unreinforced masonry and infill masonry in reinforced concrete frame construction, has shown its superiority in several recent quakes such as in Haiti and Chile. Information on confined masonry construction is continuing to be developed, both for design engineers and for builders and professionals who are working in the field. Keep a watch on the World Housing Encyclopedia (WHE) website. Regarding adobe construction, a tutorial on this construction material can be downloaded and this has recently been supplemented by the publishing of a construction manual describing how to apply straps cut from the treads of used car tyres to prevent the collapse of adobe houses during earthquakes. An article about this technology is included in this newsletter.

Since the conference has ended, for both those of who attended, and those who did not, earthquake engineering is essentially business as usual. For the most part, the way forward is to keep attending to the basics – there are no shortcuts when it comes to earthquake engineering. As far as buildings are concerned, good seismic performance begins with a sound structural configuration or layout of structural systems and elements. This needs to be followed by careful and well-checked design and detailing, and then completed by accurate and quality-controlled construction. None of these steps is easy to get right, especially in the context of a developing country. If we can work on improving each step, and if we have some success, then this will be worth sharing at the next World Conference on Earthquake Engineering, to be held in Santiago, Chile, in 2016.

Virtual Site Visit No. 30. Reinforced concrete shear walls and steel bracing

In this Issue we visit a car parking building at Auckland Airport, New Zealand. Although there is nothing particularly notable about the building from an architectural perspective, its interior structure is highly visible.

This is a four storey building of reinforced and precast concrete construction with a light-weight roof (Figure 1). From the façade the lateral load-resisting system is hidden behind horizontal and vertical panels, suggesting a moment frame in the longitudinal direction. However, once inside, the actual gravity and seismic load resisting structure is revealed.

Gravity floor loads are resisted by precast double-tee units spanning transversely and supported by reinforced concrete beams that in turn load quite short transverse walls. These walls therefore resist all gravity loads as well as transverse horizontal loads from wind and earthquake.

Fig. 3 Concentric steel bracing.

Fig. 1 A four storey car parking building.

Fig. 2 Reinforced concrete shear walls in the transverse direction.

Although the walls are quite slender, with a relatively high aspect ratio (height/length), and because the seismicity of Auckland is low, they are adequately strong and stiff for all load conditions. We can expect them to have been designed using the Capacity Design approach. So, in a seismic overload situation, ductile flexural yielding occurs in the potential plastic hinge regions at the base regions in the first storey before shear failure or any other less ductile failure mechanism occurs.

The structural system resisting longitudinal forces could not be more different in terms of material or structural form since it consists of concentrically braced steel frames (Figure 3). Several braced frames are placed along each line of gravity-only beams. A frame consists of two diagonally orientated steel tubes. Under the impact of horizontal loads, one tube will experience tension stress, while the other will be loaded in compression. The vertical components of the axial actions in the tubes will cancel out at where they meet at the mid-span of the beams.

As there are no eccentric connections or structural fuses provided, this system is not expected to possess significant ductility, so it will be designed for far higher loads than those to be resisted by the ductile reinforced concrete transverse walls. Nevertheless, this system is very suitable. From a functional perspective it allows each floor to be very open and also it would have been quick and simple to construct.

LEARNING FROM EARTHQUAKES

A summary of 'The M_w 6.9 Sikkim-Nepal Border Earthquake of September 18, 2011', an EERI Special Earthquake Report, February 2012

based on observations of the contributors listed in the original article.

Introduction

An M_w 6.9 earthquake struck near the Nepal-Sikkim border on September 18, 2011, at 18:10 local time. The earthquake triggered a large number landslides and caused significant damage to buildings and infrastructure. Sikkim was the most affected state of India, followed by West Bengal and Bihar. Neighbouring countries of Nepal, Bhutan, Tibet (China) and Bangladesh sustained damage and losses to varying extent. The maximum shaking intensity is estimated to be around VI+ on the MSK scale. The earthquake was followed by a series of aftershocks, two of which were M4.5 and M5.0 and hit within 75 minutes of the main shock.

The landslides, rock falls, and mud slides were responsible for most loss of life and damage to infrastructure, as well as associated economic losses. There was also extensive loss of Buddhist monasteries and temples; these heritage structures are built in random rubble masonry with mud mortar. Most multi-story reinforced concrete (RC) buildings were non-engineered and sustained considerable damage due to earthquake shaking; a small number of these collapsed or suffered irreparable structural damage. Poor performance and widespread damage are of concern in important government buildings, such as the secretariat, police headquarters and legislative assembly, perhaps some of the few engineered buildings in Gangtok. The total loss of life in India is reported to be 78, 60 in Sikkim, and the rest in West Bengal and Bihar. The total loss has been estimated at around US $500 million.

Buildings

Damage and losses were sustained by houses in the severely shaken areas owing to three main reasons:

slides on weak mountain slopes, rolling boulder impacts, and ground shaking-induced damage (Figure 4). In some

Fig. 4 Damage to houses due to rolling boulder at Lingzya and Chungthang (photos: Arun Menon and Rupen Goswami).

Fig. 5 above, Typical ekra house at Gangtok (photo: Alpa Sheth) below, typical house with wooden planks (Shee Khim) with damaged rubble masonry plinth (photo: AR Vijayanarayanan).

cases, the latter type of damage may have been exacerbated by the 2006 event (if the structure was not retrofitted). Scientifically based land use zoning should be undertaken to demarcate obviously unsafe sites in the state of Sikkim. Many instances were observed of soil movement under buildings on hill slopes largely made up of metamorphic and sedimentary rocks covered with soft soil.

Housing Types

The state of Sikkim has been adopting three dominant construction typologies: (1) traditional wood frame construction with ekra/bamboo-matting walling, or wooden plank construction (Shee Khim); (2) reinforced concrete (RC) construction with moment frame construction type; and (3) unreinforced masonry (URM) construction with masonry units of stone, burnt clay brick or cement blocks, mud or cement mortar, with NO earthquake-resistant features. Of the above three typologies, the third (URM) is less prevalent in recent construction, and the second (RC) most prevalent. However, most of the RC construction in the last two decades is largely non-engineered. Most buildings built in recent times in Gangtok, Chungthang, Pelling, Jorethang, Naya Bazaar and other larger towns in Sikkim are of RC.

Fig. 6 - Top image, Pancaked nine-story Dzongpo House building in Gangtok; three intermediate stories collapsed owing to sudden change in lateral stiffness (photo: Alpa Sheth);

Left image, damage to storage facility building in Chungthang (photo: Ajay Chourasia);

Middle and right image, collapsed three-story RC frame building at Singtam (photo: Alpa Sheth);

Bottom image, collapsed four-story house at Dikchu (photo: Hemant B. Kaushik).

Ekra construction consists of a wood frame with cross-woven wood matting infill panels, and a light roof. The matting is currently plastered. Another variation to this is the use of wood planks in construction by the rich. When made on flat ground, it rests on a relatively shallow and uniform masonry plinth (made of stone and mud mortar), and when made along hill slopes, it rests on a tapered stone plinth. Four varieties of stone masonry plinths are observed in Sikkim and the hills of Darjeeling: random rubble masonry (RRM) with and without mud mortar; dry dressed stone masonry; dressed stone masonry; and dressed stone masonry with pointing. In recent times, the plinth has been constructed with RC. During the earthquake, this type of housing was shaken to varying degrees, but with the exception of distress in some plinths (especially those made of RRM without any mortar), the houses performed exceptionally well. In instances where the cross-woven wood matting was replaced by clay-brick masonry in cement mortar, damage was sustained by out of plane collapse (Figure 5). The highly satisfactory performance of this housing validates its appropriateness in the Himalayan region and makes a compelling case for its continuation. This traditional style (including hybrid varieties with structurally designed basements) should be encouraged in the state of Sikkim and neighbouring states.

Reinforced concrete

There are about 13,000 RC buildings in Gangtok alone, almost 65-70% of which were built after 1995. Almost all of these buildings are non-engineered (there are only two qualified structural engineers resident in Sikkim). RC residential or hotel buildings are built on steep sloping sites on tight plots abutting each other. Only a few institutional buildings are engineered, such as government buildings, educational institutions and large hotels. RC construction performed poorly during the earthquake, even though the maximum intensity of ground shaking was only around VI+ scale on the MSK scale in most of the affected areas.

Non-engineered RC buildings across Sikkim typically have a grid of beams and columns in both plan directions. The buildings are 3-8 stories high, except in villages like Lachen and Lachung, where they are dominantly of two stories. Despite a large number of deficiencies in the RC buildings in Gangtok, one feature that may have saved them from more damage is the use of a uniform grid in most buildings. The spans vary from 3m to 4.5m, depending on the site. As these structures are on sloping ground, heights of columns vary, with some of them short columns and some slender columns. Further, because buildings are on hill sides, the width of the building is smallest at the base due to the topography. The roof of the building is partially or wholly in steel roof trusses or joists and metal sheets. The concrete for construction is hand-mixed, with neither control of the water-cement or aggregate-cement ratio, nor any systems for cube testing of concrete or testing of reinforcement.

No vibrators were being used for compaction in construction observed during the reconnaissance. The performance of RC frame buildings with unreinforced masonry (URM) infills would have been better if one brick-thick URM infill walls were used instead of half-brick-thick URM walls that either collapsed out-of-plane or were severely damaged in-plane. In cases where infills were absent or poorly built (with too many openings), the damage was significant. In RC frame buildings where the URM infill walls were made of large-sized thin cement concrete block units (350mm x 200mm x 75mm) masonry walls, the performance of the building was poor.

Buildings that had a sudden change in the stiffness pattern of the infill panel walls suffered significant damage or collapse (Figure 6). Buildings experienced torsion and collapsed when distribution of stiffness was poor in plan (Figure 6).

Masonry

Masonry construction is found especially in the British colonial government buildings in Sikkim and Darjeeling. This type has very thick walls made in random rubble stone masonry; dressed stone masonry was used in some government structures. No earthquake-resistant features are found in these structures — no bands, no through-stones, and no vertical reinforcement at corners and around openings. Unreinforced masonry (URM) was used to construct a large number of government schools and primary health centres. This stock sustained dilation of masonry starting from the upper stories.

Fig. 7 Collapse of masonry building of the primary school at Theng (photo: Arvind Jaiswal).

Nonstructural damage

This moderate earthquake also highlighted the need to address nonstructural elements (building contents, systems, facades) formally while designing buildings. Many losses were incurred in hospitals, offices, buildings, monasteries, and residential buildings. Should the next earthquake be of severe intensity, it may result in much higher loss due to nonstructural elements.

Schools

Older schools are made of traditional Ekra construction, while the recent ones (including extensions and replacements structures) are URM and RC. Ekra construction performed relatively better than RC buildings, and damage to RC schools deprived the government of safe havens for post-earthquake relief camps and emergency services. Over 600 school buildings are said to have suffered extensive damage or collapse. One complete collapse of a school building was observed (Figure 7).

Medical facilities

In most structures, pounding damage was noticed at construction joints; frame-infill separation, cracking of plaster and diagonal cracking on infill walls were observed RC frame buildings, as was damage due to incorrectly detailed seismic joints. Some government buildings and hospitals in the state sustained nominal damage and could have been used after the earthquake, but were "declared"unsafe and ordered to be demolished without professional inputs of engineers conversant with safety assessment protocols. This caused severe disruption to medical service, relief operations, and governance continuity.

Lessons Learned

This earthquake has brought into relief issues of disaster mitigation and management in the inhospitable region of the Himalayas which is one of the most seismically active regions of the country.

1. The extent and type of damage in newly built RC structures are not commensurate with the in tensity of ground shaking. Most damage can be attributed to irregular structural configuration, improper design and detailing, poor construction materials and practice, or complete absence of regulatory framework from the government side to ensure earthquake-resistance in the built environment.

2. No new URM structures should be permitted in Sikkim, and existing ones should be retrofitted, especially the critical, life-line and government structures.

3. Develop a comprehensive plan to Sikkim and West Bengal. When even basic earthquake-resistant construction is not known by local architects and engineers, special assistance may be required from outside these states to support this culturally and historically critical work.

4. There should be an aggressive promotion of traditional Ekra housing by development of a manual of good construction practices and inclusion of this as a formal housing construction typology eligible for bank loans.

5. Post-earthquake damage assessment teams need to be mobilized from out of state that have sound judgment on usability of damaged structures and no stake in the new construction. As well, technical information needs to be disseminated to professional architects and engineers on accepted methods for assessment and retrofit of damaged structures.

6. Document all losses incurred by nonstructural elements, and disseminate technical know-how to architects and engineers on methods of protecting these elements.

A summary of "Tyre Strap Seismic Reinforcement for Adobe Houses"

by A.W. Charleson, *School of Architecture, Victoria University of Wellington, New Zealand*, presented to the 15th World Conference on Earthquake Engineering, Lisbon, September 2012.

Introduction

Of all housing construction types worldwide, earthen construction is among the most fragile with respect to horizontal loads experienced during earthquakes. Although there are many different types of earthen and related construction, including random rubble and dressed stone construction either laid dry or in mud mortar, they all share two serious structural deficiencies: (1) of having little if any tension strength, and (2) brittleness. As tragically witnessed after every damaging earthquake in developing countries, due to their high mass and lack of tensile resistance that has the potential to tie the elements of buildings, like walls together, the seismic performance of these forms of construction is very poor. Tyre strap reinforcement is one response to this unfortunate situation. The basic steps of the application of tyre strap technology is summarized visually in Fig 8.

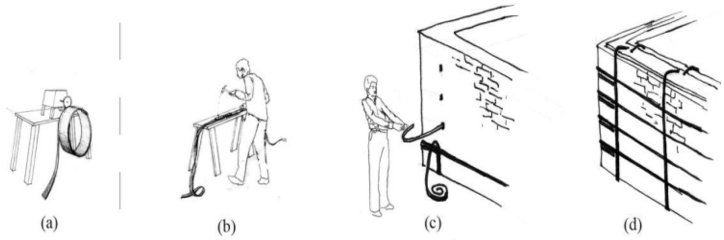

Fig. 8 Steps in the process of reinforcing an adobe house with tyre straps. Step (a) is performed in a workshop or factory and (b) to (d) on site. (Courtesy Matthew French)

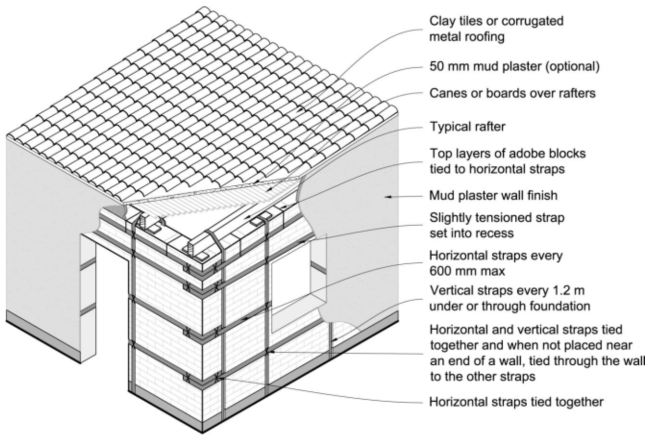

Fig. 9 The main features of a strap-reinforced house.

The concept at the heart of this reinforcement system is for tyre straps to be cut from discarded used tyres in developed countries (where used tyres are generally not too badly damaged and worn and may be costly to dispose of) and then donated and transported to developing countries, where at minimal cost homeowners incorporate them in new or existing houses. Two very desirable outcomes eventuate: both existing and new adobe buildings are strengthened at minimal cost with a material that is simple to install and plentiful in supply, and a significant portion of used car tyres are recycled in an environmentally acceptable manner.

In this system, the circumferentially cut straps from the treads of used car tyres that function as tension reinforcement must be cut from steel-belted radial car tyres. Although the steel wires in the two belts are not continuous they give the straps sufficient strength and stiffness to be used as reinforcement.

After approximately six metre-long and 40 mm wide continuous straps have been cut from tyre treads, they are connected on site using a special yet simple nailed joint. Once the walls of a house are constructed and holes drilled or formed during construction to allow straps to pass through, straps are then wrapped horizontally around walls at 600 mm centres maximum vertically. Vertical straps spaced horizontally at approximately 1.2 m centres pass underneath or through the foundations, then rise up both sides of the walls, wrap over them and are connected and finally nailed to roof timbers. This type of reinforcing pattern is designed so as at least one pair of straps, either vertical or horizontal, cross every large potential crack that will open during an earthquake. The reinforcement provides structural strength and tying-action after the earthen wall material has failed. Figure 9 illustrates the main features of the system.

This system is suitable for new and existing earthen houses in areas of moderate to high seismicity. It could also be employed shortly after a damaging earthquake to enable seismically resilient reconstruction to proceed using materials salvaged from badly damaged and collapsed houses. Until further research is undertaken it is proposed that strap reinforcement be applied to earthen houses whose designs broadly comply with the most recent unreinforced adobe construction guidelines.

Technical Development of the Tyre Strap Reinforcement

Tensile tests have been conducted on tyre straps cut from the treads of radial steel-belted car tyres. Test results confirm that given the necessity for desirable strength and stiffness, and the need to avoid short strap lengths with large numbers of connections, 40 mm wide straps are the most suitable.

They possess tensile strengths between 10 - 15 kN. Straps are butted together and connected via two short lengths of overlapping straps to form a butt joint (Figure 10). The nails are bent carefully to prevent a premature nail pull-though failure mechanism of the joints.

Initial load tests using the tyre straps for in-plane and out-of-plane test specimens on dry-stacked brick walls were successful. They indicated the potential of the system to provide large amounts of ductility and so the system was further developed for use in adobe construction. A small single room full-scale adobe house was built and reinforced and subjected to four phases of earthquake shaking on a uni-directional shaking table (Figure 11).

Assuming there is no cost for the tyre straps, the cost of materials to provide straps to a small 52 m2 four roomed house has been estimated as US$378. Almost 65% of this cost is for the wall finishing paint.

Costs of Materials and Labour Requirements

An estimate of time to complete each construction activity was based on the times taken to reinforce the one room module that was dynamically tested. In that case one experienced mason worked with a person with little building experience. It is feasible for most of the work to be undertaken by an unskilled worker or the house owner, with occasional supervision by a mason. The total time required to install the straps and complete the work will vary due to many factors, including the quality of the equipment and the speed and efficiency of the workers. For the single-roomed test module with a gross area of $10m^2$ and average wall height of 2m the estimated times are shown in Table 1.

The module that was reinforced and tested had 250 mm thick walls with an average height of 2m and a gross area of approximately $10m^2$. The time taken to reinforce a larger house can be approximately determined on a pro rata basis. Extra time needs to be allowed for if walls are thicker and higher, and if there are gable ends and/or parapets. No allowance is made for painting or repainting all the interior and exterior surfaces.

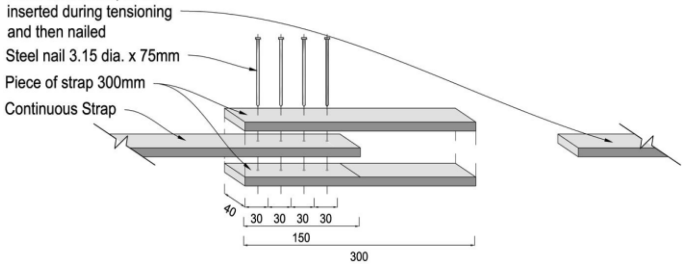

Fig. 10 A nailed strap joint. Both ends of the nails are bent during nailing.

Fig. 11 The adobe test module on the shaking table.

Steps	Construction activities	Worker days
1	Mark the position of horizontal straps and vertical straps using chalk.	0.5
2	Cut rebates into adobe walls to accommodate straps.	2.0
3	Form holes under/through foundations for vertical straps.	1.5
4	Drill 50 mm by 10 mm holes at wall corners for horizontal straps to pass through, and paint exterior rebates for straps.	2.0
5	Remove areas of roof and ceiling to pass vertical straps over rafters.	1.5
6	Place, cut, tighten, connect vertical and horizontal straps (requires two workers). Apply corrosion protection to vertical straps where they pass under the foundations.	9.0
7	Drill 5 – 10 mm dia holes through walls, tie straps together and provide ties to top course of adobe blocks.	1.5
8	Plaster over straps with mud mortar. After mortar is dry, paint over the straps with water-resistant paint.	1.5
9	Miscellaneous	1.0
	Total	20.5

Table 1. List of construction activities and worker days.

A more detailed and comprehensive paper is available in the article ‘Seismic reinforcement for adobe houses with straps from used car tyres’, *Earthquake Spectra* **28:2, 2012**.

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/