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Contents

Editorial

Satisfaction in Earthquake Engineering

In the last issue I identified some of the frustrations associated with the practice of earthquake engineering. A number of irritations were mentioned. Essentially they stem from the fact than our work focuses upon natural disasters with low probabilities of occurrence. Many people, especially some building owners, prefer to deny the likelihood of such damaging quakes ever occurring. To the list of irritations I could have added one more; most of our skillful work is hidden from view.

Nobody, except for a few construction workers over a period of a several days, sees those special ductile members or connections we sweat over during design. No one can tell from the outside, whether a column we have designed will behave in a ductile manner when the building sways during an earthquake, or whether it will fail in shear and then at least partially collapse due to the gravity load it carries. Neither can more than one or two people appreciate how, in collaboration with the architect, we transformed an irregular and vulnerable structural configuration into one whose seismic performance is far more likely to be satisfactory. Lives may be saved and certainly earthquake damage costs reduced greatly.

Such hidden work lies dormant until the next quake. Even then its structural effectiveness may be taken for granted because of society's deep seated unrealistic expectations of 'earthquake proof buildings'.

Our efforts are rather like those of a baker adding yeast to dough to make bread rise. The skilful addition of a small amount of that ingredient transforms something unpalatable into food that is delightful to eat. So we, who design and supervise earthquake resistant buildings, take buildings as well as methods of construction that are potentially unsafe in an earthquake, and by careful design and detailing transform poorly performing structures into ones with resilience and ductility. By applying Capacity Design principles we determine where buildings' strength will be exceeded and then ensure those areas susceptible to damage are well confined. It is vital that those 'fuse' regions don't lose too much strength during a quake's cyclic loading, nor that other members, especially the columns that carry the entire weight of a building, are damaged.

Satisfaction arises from applying our knowledge to save lives and reduce economic losses. In the words of the famous U.S. architect Frank Lloyd Wright, the aim of earthquake engineers is to “outwit the quake”. The satisfaction of earthquake engineering resides in the knowledge that we are contributing to the safety and sustainability of our clients and society at large.

An earthquake strikes the Solomon Islands

On April 2nd 2007 a Magnitude 8.0 quake occurred in the vicinity of the Solomon Islands. Compared to other recent large quakes, the loss of life is low in these relatively sparsely occupied islands, yet the survivors are having to cope with terrible destruction. Not only did the earthquake shaking damage many houses and other buildings, but a tsunami devastated low-lying areas. The strength of the quake was such as to uplift some islands as much as three metres, destroying their coral reefs and with them, the livelihood of many of their inhabitants. Relief efforts are underway.

None of us in seismically active regions should be complacent.

Virtual Site Visit No. 8. Reinforced concrete shear walls, Wellington

A multi-storey building currently under construction relies on shear walls to resist transverse wind and seismic forces. Fig. 1 shows the four cantilever walls designed for lateral loads. Strong in the direction of their length, they rise from the fixity provided by strong and stiff foundations to cantilever up to the top of the building.

Three of the walls are rectangular in plan, with the fourth being I-shaped. Its end thickenings provide space for the vertical tension steel required to resist the base bending moment-induced tensions. The thickenings also increase the wall breadth to prevent buckling that could be caused by the combination of gravity forces in the wall and bending moment compression. The thickness of the walls, approximately 600 mm, reflects the high shear forces that must be resisted. Wall shear strengths are designed so that ductile plastic hinging at wall bases occurs before brittle shear failure.

Fig. 1 General view of the site and the cantilevered reinforced concrete

Fig. 2 illustrates the concentrated volume of reinforcing steel in the end regions of a wall. The horizontal shear reinforcement in the wall web is anchored in these areas and all the vertical steel is well confined by horizontal ties. The lowest two storeys of these walls are where plastic hinges will form during the design earthquake.

Since the cover concrete will fall away at each end of a wall, horizontal confining steel is essential to prevent the vertical steel buckling under compression and also to avoid large chunks of concrete falling out of the wall, causing its strength to degrade.

Fig. 2 A wall with its formwork open to reveal the reinforcing layout at the end of the wall.

While the transverse lateral forces are resisted by the four walls, two perimeter moment frames resist longitudinal forces. Columns and beams of these frames have not yet been cast, but Fig. 3 shows the reinforcement of a typical column. Note how almost every perimeter bar is restrained against horizontal buckling by a leg of a tie. There are six transverse legs along the depth of the column and four running in the orthogonal direction. All ties possess 135 degree bends and sufficient anchorage length into the concrete core. When they are subjected to tension due to their dual role of resisting shear as well as providing confinement to vertical reinforcing and concrete following the loss of cover concrete, their strength will be maintained.

Fig. 3. The vertical and horizontal reinforcement of a typical moment frame column.

Summary of "Performance of structures during the Sikkim earthquake, India, 14 February 2006"

by Hemant B. Kaushik, Kaustubh Dasgupta, Dipti R. Sahoo and Gayatri Kharel. From *Current Science*, Vol. 91, No. 4, 25 Aug 2006.

Introduction

Performance of structures in different areas of Sikkim, during the earthquake of 14 February 2006, is reviewed. The earthquake caused damage to heritage structures as well as modern buildings. Both masonry and reinforced concrete buildings showed poor performance. On the other hand, traditionally constructed wooden houses performed extremely well. The damage seen in and around Gangtok was clearly disproportionate to the size of the earthquake, which was a moderate 5.7 on the Richter scale. This very clearly establishes the high level of seismic vulnerability of the region. The damage is primarily attributed to poor design and construction practices, and lack of quality control. Urgent need for trained human resources and for creation of a system of checks and balances, to ensure safe constructions in Sikkim is highlighted.

A moderate earthquake (reported as M_w 5.3 by USGS and as M_L 5.7 by IMD) occurred in Sikkim (India) on 14 February 2006 at 06:25:23 am local time with a focal depth of 33 km. Shaking was also felt in the northeastern states of India and the neighbouring countries. Most of the structural damage was observed in and around the state capital Gangtok, with the maximum intensity of shaking as VII on MSK scale.

It was common practice in Sikkim to construct residential buildings using wood/bamboo, until the tourism industry got a boost in the early nineties. Such traditional constructions performed well during ground-shaking. Most old buildings in Sikkim are made of stone masonry with mud mortar. Stone-masonry buildings suffered substantial damage during the present earthquake, and several of these were evacuated. Presently, RC-frame buildings with masonry infills are mostly used in private as well as government constructions. There is no formal design practice in Sikkim even for RC-frame buildings. Except for a few RC buildings involving major projects, analysis and design are generally not carried out; structural drawings are prepared simply based on previous experiences of engineers on the basis of a few rules of thumb. Most of the new RC buildings in Gangtok suffered varying degrees of damage during this earthquake; however no complete collapses were seen. Traditional construction in Sikkim consists mostly of typical bamboo houses, known locally as 'Ikra', and also known as Assam-type housing. Ikra houses are single-storey structures consisting of brick or stone masonry walls up to about 1 m above the plinth (Figure 4). This masonry supports the walls consisting of bamboo woven together with a wooden frame, and plastered with cement or mud plaster. The roof generally consists of GI sheets supported on wood/bamboo trusses, which laterally connect the parallel walls. Bamboo superstructure is connected to the masonry foundation walls using steel angles, and flats with bolts and nails. There were no reports of any significant damages to Ikra structures during this earthquake.

Fig. 4. Traditionally constructed typical Ikra structure in Sikkim (school building at Nandok, East Sikkim).

Generally, stone-masonry structures in the area are of undressed stones with mud mortar. Stone-masonry buildings suffered damage primarily because of undressed stones used without proper bonding between adjacent courses of masonry, and also at the corners. The mud mortar used as bonding material in these buildings further aggravates their lateral strength capacity.

The two-storey Archive building was previously the Legislative Assembly building at Gangtok, until it was damaged during the 1988 Bihar–Nepal earthquake. Subsequently, this masonry building was retrofitted by fixing horizontal and vertical steel flats of about 50 mm x 8mm size on all the outer faces of the exterior walls in each storey (Figure 5). The building sustained no damage during the present earthquake. Clearly, sensible retrofitting of

Fig. 5. Good performance shown by retrofitted Archive building (arrows show steel flats used to retrofit the building after the 1988 Bihar–Nepal earthquake).

important heritage structures can be critically useful in the future earthquakes.

In rural areas of Sikkim, low-cost school buildings are generally constructed by the state government using stone masonry with mud mortar. Several such buildings suffered severe damage during the present earthquake. Earthquake resistant features such as horizontal bands at various levels and stones at the corners are generally not provided in such construction. This resulted in the formation of severe cracks near the corners and at the location of openings in such buildings, when subjected to even mild shaking (Figure 6). In addition, out-of-plane tilting of several masonry walls was observed at some places.

Fig. 6a, b. Severely damaged stone masonry low-cost school buildings in Sikkim. (Government Primary School, Thamidara near Gangtok).

In RC buildings, burnt clay bricks or solid/hollow concrete blocks are commonly used as infills. Noticeable features of this type of construction are (i) absence of RC lintels above doors and windows in private buildings (brickwork is generally supported directly by the wooden frame used for doors/windows), (ii) floating columns in upper storeys, (iii) intermediate soft storey in multi-storeyed buildings, and (iv) poor reinforcement detailing. Quality control of materials was observed to be poor in most buildings.

Most RC buildings at Gangtok suffered damage of some form or another, the most common being cracks in masonry infills, and separation between RC frame and infill. Another four storey RC building at Deorali suffered damage and was evacuated. Severe damage was observed in several RC columns of the building, exposing mild steel bars as main reinforcement (Figure 7 a and b). Poor material quality and poor connection between perpendicular masonry walls resulted in out-of-plane failure of one infill wall, and severe damage to other infill walls in the building (Figure 7 a and c).

Fig. 7. Damage in residential building at Deorali. a, Severe cracking in infill walls and damaged RC column. b, Exposed mild steel in damaged RC column; and c, Out-of-plane failure of infill wall.

Similar damage to infills and RC members was noticed in several other government and private RC buildings in the eastern and southern districts of Sikkim. A part of the recently constructed three-storey RC government secondary school building at Sichey was found to be damaged. One masonry infill wall in the first storey tilted out-of-plane along with cracks in several other infills. In several RC columns of the building, spalling of cover concrete due to corrosion of reinforcement bars was observed along with inadequate shear reinforcement.

The present study puts a maximum intensity of shaking as VII (on the MSK scale) in the worst affected areas of Sikkim during the recent earthquake of magnitude ~5.3–5.7. In the absence of proper design and construction methods and lack of quality control, masonry buildings and RC-frame buildings have performed rather poorly. This indicates a high level of seismic vulnerability of the region. Discontinuous RC columns were commonly observed in several RC-frame buildings in Sikkim; therefore a RC-frame lateral load resisting system could not be developed. Such design and construction practices have severe consequences as seen in Ahmedabad during the Bhuj earthquake of 26 January 2001. Traditionally constructed bamboo structures (Ikra) have performed well during this earthquake. Good construction practices need to be propagated and the seismic codes need to be enforced. People (including engineers) need to be sensitized about basic construction issues, and seismic hazard associated with the region of Sikkim. Another urgent requirement is training and supply of simple literature to government as well as private engineers and to local people on how to incorporate simple techniques in RC and masonry buildings to make them earthquake-resistant. Considering the high seismic hazard in the area, this moderate earthquake has highlighted the urgent need for proactive actions to propagate safe construction practices.

Summary of “Seismic Vulnerability of Non-Engineered Houses in Caracas (Field Experiment and Seismic Evaluation)”

by Mitsuo Miura, Akira Inoue, et al. from Proceedings of the 8th U.S. National Conference on Earthquake Engineering, April 18-22, 2006, San Francisco, California, USA.

Introduction

Many non-engineered houses, called Barrio houses, have been built on the slopes of hills in Caracas (Figure 8a). The main frames are made of reinforced concrete with infill clay hollow brick walls. There are approximately 230,000 Barrio houses in total, half of which are constructed on slopes of more than 20 degrees, and they house approximately 1.3 million people. Most of the houses have been built recently and have not experienced severe earthquakes. This paper examines their structural capacity and the feasibility of seismic reinforcement, and describes a seismic evaluation.

The objectives of the field experiment were as follows:

- To assess the vulnerability of Barrio houses
- To assess the effect of seismic reinforcement for Barrio houses, using available techniques and at an affordable cost

An example of a Barrio house built on a slope is shown in Figure 8. This house has reinforced concrete columns for the lower storey and has frames with brick walls for the upper storey. This was used as a reference for the base model. A one-storey Barrio house with columns at a lower layer built on a slope of approximately 20 degrees was selected as the base model of the field test. A full-scale model was used for the test to reproduce the actual conditions of non-engineered houses. The dimensions of the model were 2.8 m x 3.8 m in column span (center to center of columns), and storey height of 2.4 m for the upper floor and 2.4 m for the lower floor (lower side of slope). Foundation sizes were 1.0 m x 1.0 m x 0.2 m.

Fig. 8a, b. Barrio houses on the slope of a hill.

Seismic Reinforcement and Cost Impact

There are two main methods of seismic reinforcement: one is to improve strength and the other is to improve ductility. Strength improvement was used in this case. Criteria for selecting seismic reinforcement such as technical aspects and economical feasibility were considered. As a result, grade beams, clay hollow brick walls and concrete block walls, which can all be purchased easily and locally, were chosen.

Four models were constructed and tested. The cost impact and strengthening method are summarized in Table 1. One side of the concrete block walls of Model 4 had vertical and horizontal re-bars.

Table 1

No.	Strengthening	Cost impact	Strengthening method
1	No	0%	None
2	Yes	5 to 7%	Grade beams
3	Yes	10%	Grade beams & brick walls
4	Yes	15%	Grade beams & concrete block walls

Grade beams were the same size as beams and the connection to columns was detailed so that they could be installed after construction of the columns (Figure 9). A column clear length of 600 mm (3 times the column width of 200 mm) was maintained between floor beam and grade beam (upper side of slope). The weight of the model for seismic assessment was 96 kN (9.8 tonf).

Fig. 9. Provision of grade beams on slope

Aspects of Non-engineered Works during Construction of Models

The following aspects of non-engineered works that have been observed were incorporated into the construction of the model houses to replicate the actual condition of existing buildings.

1) **Concrete mixing** - Concrete mixing was 'home-made' and done by hand based on experience.
2) **Fabrication of hoop re-bars -** The hook of the hoop re-bars was 90 degrees, rather than the 135 degrees required for seismic performance.
3) **Lap length of re-bars -** The lap length of column re-bars was short, due to a lack of engineering coordination of re-bar arrangement and the position of construction joints.
4) **Concrete cover -** Exposure of column main re-bars and no concrete cover, which reduces the durability of columns, was observed. This is due to a lack of engineering coordination of hoop (re-bar) size, formwork size and coarse aggregate size of concrete.
5) **Re-bar anchorage -** Shortage of anchoring of beam re-bars to columns was observed, with beam main re-bars stopping at the outer face of formwork. Improper arrangement of re-bars at the joints of beams and columns was also observed

Material Test

The results of concrete cylinder tests at 28 days recorded an average strength of concrete for beams/columns that was only 5.7 N/mm^2, which is about one third that of normal engineering concrete.

Horizontal Loading and Measurement

The completed four models are shown in Figure 10. Horizontal load was applied at floor level in the direction of the slope through two synchronized hydraulic jacks.

Fig. 10. The four completed models(above) and loading frame (below).

Results of Experiment

Model 1 - The failure mode of the model 1 frame was column flexural collapse and plastic hinges were provided at the tops of columns.

Fig. 11. Flexural failure of short column (above) and flexural failure of long column (below) of Model 1.

Model 2 - The failure mode of short columns was flexural/shear mode at yield strength and shear failure occurred at the later stage. The failure mode of long columns was flexural failure, while shear diagonal cracks were also observed.

Fig. 12. Shear failure of short column in Model 2.

Model 3 - Separation of clay hollow brick walls from columns and beams appeared from the beginning of loading and the combined effect with frames was not expected. It was found that clay brick walls did not significantly contribute to stiffness and strength compared to those of Model 2.

Fig. 13. Test results of Model 3

Model 4 - Separation of hollow concrete block walls without re-bars from columns and beams started at an early stage of loading from 60 kN to 70 kN.

Fig. 14. Test results of Model 4

Summary of the Tests

1)The strength of frames without reinforcement was 88 kN to 98 kN.

2)Providing grade beams is effective and increases the strength by approximately 40%, but to prevent shear failure care is needed to ensure a clear length of columns. The cost impact is from 5% to 7% of new construction.

3) Clay hollow brick walls are not effective for seismic strengthening. The cost impact is 10%.

4) Concrete block walls will be effective if the blocks are made stronger and re-bars are used. Drilling and epoxy grouting are suggested for anchoring re-bars to existing columns/beams. The cost impact is 15%.

Summary of "Preliminary Observations on the Taiwan Earthquake of December 26, 2006,"

from EERI Special Earthquake Report - February 2007. This report is compiled from observations made by a reconnaissance team assembled by the National Center for Research on Earthquake Engineering (NCREE), and by the National Science and Technology Center for Disaster Reduction

Introduction

At 8:26 p.m. local time on December 26, 2006, a M_L 6.7 (M_W 7.1) earthquake rocked the southern coast of Taiwan, about 22.8 km southwest of Hengchun (90 km from Kaohsiung). Eight minutes later, a large aftershock (M_L 6.4 [M_W 6.9]) hit the region, followed by a second aftershock (M_L 5.2) at 8:40 p.m. Most buildings survived without any damage, but a few street-front commercial/residential buildings, hotels, and elementary schools sustained moderate to severe damage. A four-story furniture store with a possible soft story collapsed, three apartment buildings collapsed, 134 schools were damaged and several fire outbreaks were reported. There were two fatalities and 45 people injured. The earthquakes also damaged several undersea fibre-optic cables used to route internet and telephone services; this disrupted business in Taiwan, Hong Kong, Japan, China, South Korea, Philippines, Malaysia, Singapore, and Thailand.

Structures

Commercial/Residential Buildings:

The four-story collapsed furniture store with residential upper floors was constructed in the early 1980s. The brick walls were first erected and then reinforced concrete columns, beam, and slab were constructed using the brick wall as part of the formwork (reinforced masonry building). The total width and length of this building is 7 m x 23 m, respectively. The first floor of this building was for commercial use, and the rest of the floors were residential. Large openings for doors and windows were located at the street sides of the building. The frames above the ground floor were infilled with a brick masonry perimeter and partition walls. Thus, the bottom floor was comparatively weak due to the open front and open space. Figure 15 shows the schematic plan views of the building. There were a total of 15 columns. Along the long axis, the number of spans ranged from four to six; along the short axis there were one to two spans. There was obviously not enough redundancy. Most of the brick walls were located on the right side along the long axis, which made the planar lateral stiffness asymmetric. Figure 16 shows the collapsed building after the main aftershock. A few other street-front residential buildings were also damaged. Brick walls and beams were seriously stressed, and the interior ground was cracked.

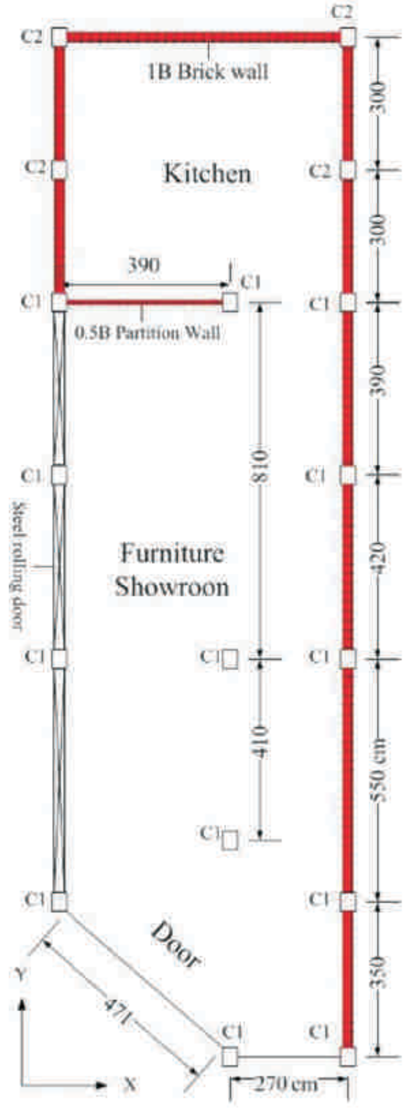

Fig. 15. Floorplan of the 4-story furniture store.

School Buildings:
Damage to school buildings was significant in Pingtung County. Most school buildings in Taiwan at the primary and secondary levels usually lack engineering, and they are constructed and expanded in a patchy way. It is easy to see that the structural systems of school buildings have intrinsic defects. Classrooms are generally located side by side in a row. The plan of each classroom is about 10 m in width along the corridor and 8 m in depth perpendicular to the corridor. The corridor may or may not be cantilevered. The stiffness in the direction perpendicular to the corridor is much higher than that along the corridor. In order to utilize the natural light and ventilation, windows and doors fully occupy both sides of the corridor. At the upper portion of the columns, they are constrained by the window frame made of aluminum or wood. The lower portions of the columns are constrained by the windowsill made of brick walls. Since the windowsill is rigid compared with the window frame, the effective length of the column is shortened. The shorter the column, the larger the shear force. Therefore, the columns tend to fail in the shear mode rather than the flexural mode.

Fig. 16. Side view of the collapsed furniture store.

Announcement

1ECEES Downloads

A number of free downloads are available from the web page www.ecees.org of the First European Conference on Earthquake Engineering and Seismology (1ECEES) that took place in Geneva, Switzerland, in September 2006.

The main documents are (1) 2000 abstracts at http://www.ecees.org/abstracts_book.pdf; (2) PowerPoint presentations of the ten keynote lectures, videos of presentations and the pdf files of keynote papers at http://www.ecees.org/index2.html (press "keynotes" in the menu); and (3) other documents, including the order form for the CD with the proceedings.

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Promoting Earthquake-Resistant Construction in Developing Countries
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