EARTHQUAKE HAZARD CENTRE
NEWSLETTER
Supported by Robinson Seismic Ltd
www.robinsonseismic.com

Vol.7 No.1 JULY 2003 ISSN:1174-3646

Contents

Editorial

Welcome to Pacific Islands readers

The Earthquake Hazard Centre is in the process of significantly increasing the newsletter circulation within the Pacific region. This initiative recognizes the relatively high levels of seismic risk in the area, but in particular responds to the interest and concern of the New Zealand Ministry of Civil Defence and Emergency Management. The Ministry, a new co-sponsor of the Centre is assisting reduce the region's vulnerability to natural and other disasters. Given the frequent occurrence of tropical storms and cyclones in the Pacific we will be pleased to receive and publish information on improving resilience to that risk as well as the risk from earthquakes. If you are aware of any helpful information, recent research findings or examples of best practice for any of these risks, please get in touch.

Indian earthquake engineering education initiative

The Ministry of Human Resource Development has announced a National Programme on Earthquake Engineering Education (NPEEE) to develop capacity within Indian engineering and architectural institutions. The emphasis of this three year project is upon the training of teachers and earthquake engineering curriculum development.

With memories of the devastating 2001 Bhuj earthquake still fresh, the initiative aims to improve the current situation. Earthquake engineering is not included in typical undergraduate curricula but is considered a *super-speciality* within the civil engineering profession.

Initially, the top eight educational institutions will undertake the following primary activities:

- Short-term and medium-term training of teachers
- Provision of library resources to 100 institutes and several limited laboratory upgrades
- International exposure through a combination of local individuals attending overseas courses and training, and input from invited visiting international experts
- Development of curricula, teaching aids, course materials, textbooks, manuals and commentaries to codes.

The significant size of the budget (US$ 6million) indicates how seriously this initiative is being taken. Although the first phase of the programme has a three year duration it is hoped that the work will continue many years into the future.

The Earthquake Hazard Centre congratulates those who have envisioned the project and are now beginning to implement it. This is a marvellous precedent for the upgrading of earthquake engineering practice, and one that will hopefully be adopted by other countries in due course.

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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. It is supported financially by Robinson Seismic Ltd and the Ministry of Civil Defence and Emergency Management.
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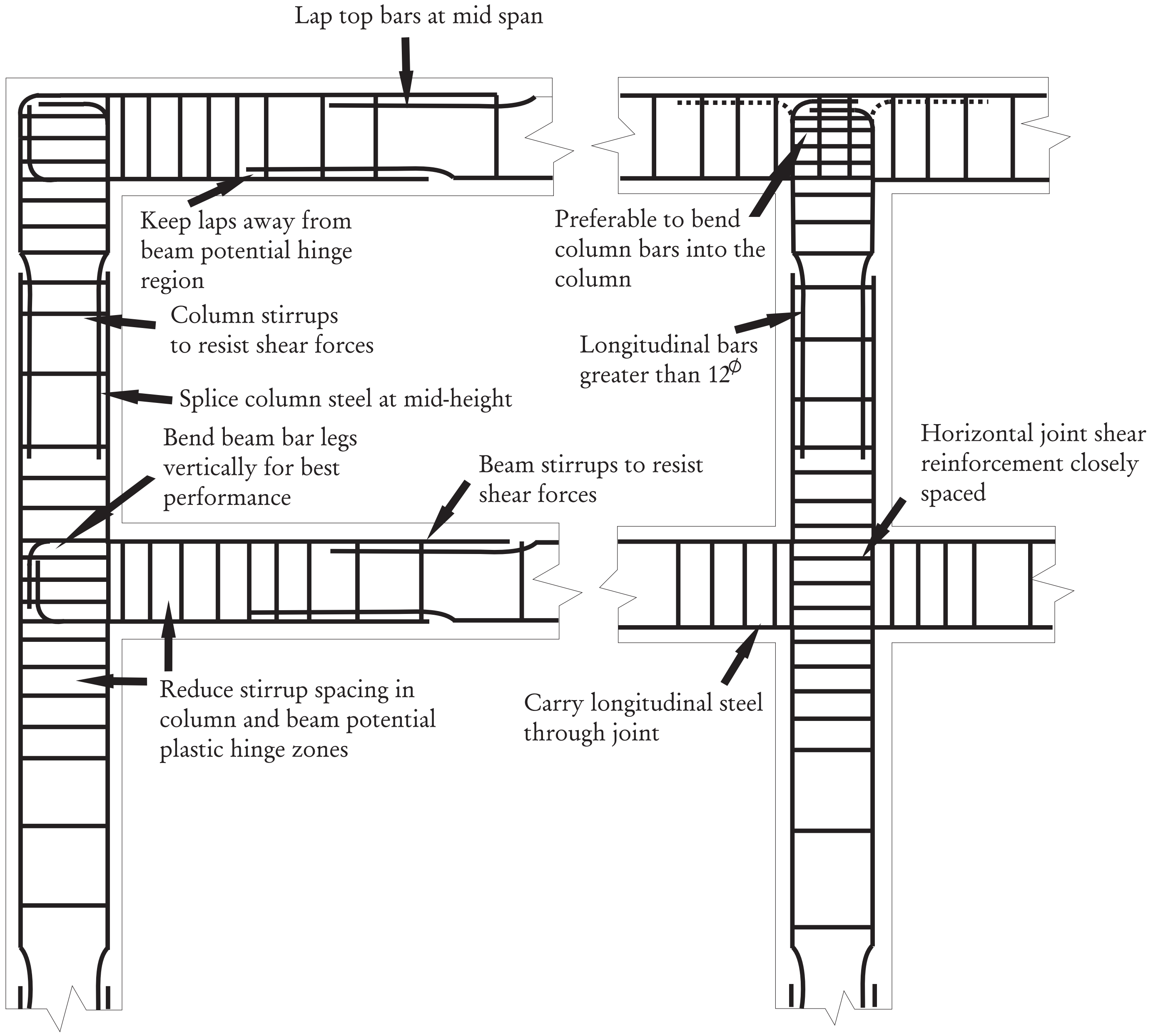
Principles of Building Earthquake Resistance No. 25

An interior check-up of moment-resisting frames

In the last newsletter we looked at the relative dimensions of beams and columns that form effective seismic resisting frames. Now we focus upon the internal reinforcement that is necessary for reliable seismic resistance.



Typical column section

Typical beam section

For detailed information refer to local Codes of Practice and manuals

A summary of article "An experimental study of effectiveness of seismic and retrofitting measures in stone masonry houses", by Pankaj Agarwal and Shashi K. Thakkar, Department of Earthquake Engineering, IITR, Roorkee, India, from *European Earthquake Engineering 16(3) 2002.*

Stone masonry is one of the most traditional and oldest materials of construction in hilly and rural parts of India. Past earthquakes that have occurred in the Indian subcontinent particularly Uttarkashi, 1991, Killari, 1993, and Chamoli, 1999 reveal that the root cause of devastation is the collapse of stone masonry houses. Therefore, the earthquake resistance of such construction should be enhanced. Strengthening and retrofitting are the two most vital issues for minimizing disaster. Strengthening implies incorporation of earthquake resistant features in the structural system of a newly constructed building that improves its seismic resistance by increasing strength and ductility.

We carried out a series of tests on full-scale single storey random-rubble stone masonry models under progressively increased intensity of shocks on a shock-table facility. The purpose of this study was to evaluate existing IS code techniques of strengthening and retrofitting measures and to propose upgrading these methods to achieve better performance in earthquakes.

Models for strengthening and retrofitting measures
Six stone masonry models in random rubble are tested on a shock-table facility to study the effectiveness of codes providing for earthquake resistance measures. One model is built in a traditional way without any strengthening measures while the other models featured gradually increasing strengthening arrangements like roof, lintel and sill bands, and corner reinforcement. Two damaged models are retrofitted by combinations of two different techniques.

Design and Construction of Model
The model is single storeyed one room house measuring 2900x2600x2700mm and thickness of walls is 400mm constructed in random rubble stone masonry. The layout plan and section of the model is given in Figs. 1 and 2

The method of strengthening recommended in IS code is based on the following concepts:

- Need of integral action,
- Strong and ductile connections between walls, roof elements and foundations,
- Improvement in strength for out-of-plane bending,
- Strengthening of weaker sections by steel, timber or reinforced concrete and
- Improving the strength of mortar and quality of construction and insertion of bonding elements.

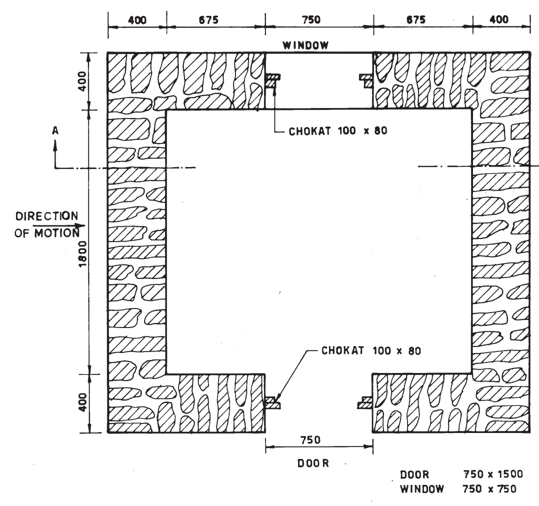


Fig. 1 Plan of model house

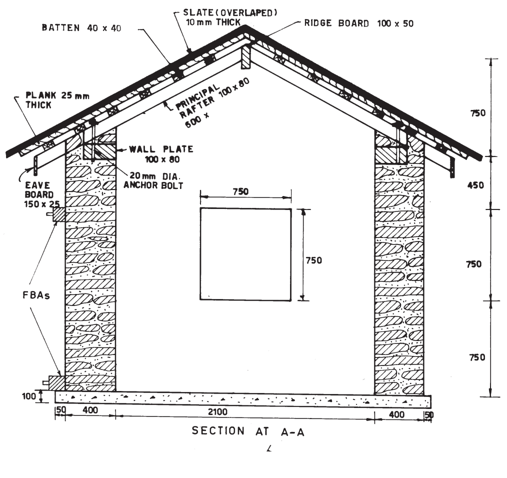


Fig. 2 Section through model house

The Indian Standard Code IS: 13828: 1993, *Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines* furnishes the details of strengthening measures. The function and brief description of each strengthening measure are summarized as follows:

Mortar: The stone masonry of random rubble or dressed stone type should be constructed in cement-sand (1:6), lime-sand (1:3) or clay-mud of good quality.
Wall Dimensions: The height and length of the wall should be less than 3m or 5m respectively. The wall thickness should not be larger than 350mm and inner and

outer wythe interlocked with bond stones. The bond stones (through-stones) of full-length equal to wall thickness should be used in every 600mm lift at not more than 1.2m horizontally.

Wall Openings: Door and window openings in walls reduce their lateral load resistance and hence should preferably be small, not more than 40% of wall area, and placed centrally. If openings do not comply with the code, they should be strengthened by reinforced concrete lining with 2 high-strength deformed bars of 8mm diameter.

Seismic strengthening features

The building should be strengthened by horizontal bands or bond beams at critical levels and vertical reinforcing bars at corners and junctions of walls. The bands form a horizontal framing system, which transfers the horizontal shear, induced by the earthquakes from the walls normal to the direction of shaking to structural walls parallel to the shaking, and it also connects all the structural walls to improve integral action. In combination with vertical reinforcement, they improve the strength, ductility and energy dissipation capacity of masonry walls. Fig. 3 shows the details of horizontal bands at the level of the roof, lintel and sill. Fig. 4 furnishes the details of providing the vertical reinforcement in stone masonry.

Fig. 3 Detail of horizontal band

Fig. 4 Wall vertical reinforcing steel

Shock table tests on models

The facility consists of following components:

- Railway track,
- Shock table,
- Dead-load wagons or striking wagons,
- Winch mechanisms to pull wagons

The loaded wagons are placed on the track on both sides of the shock table. One of the loaded wagons is allowed to roll down the gentle incline, impact through springs and thus drive the shock table into collision with the other dead-load wagon. The general arrangement of the shock table and its signature of shock are given in Figs.5 and 6.

Fig. 5 Shock table facility

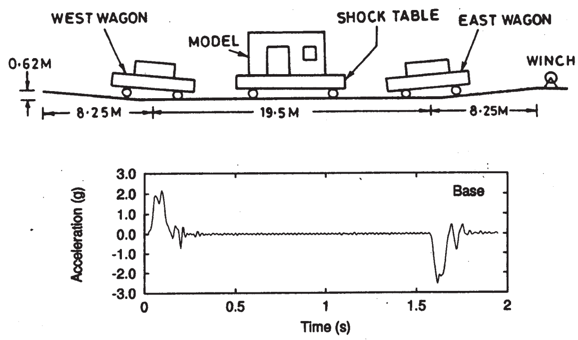


Fig. 6 Layout of shock table facility and signature of main shock and rebound

Shock test results are shown in Figs. 7 to 10.

Conclusions

Through the number of tests are too few to make generalized conclusions about the behaviour of stone masonry building under earthquake type motion, some important conclusions can be made on the shock response of stone masonry models and are highlighted below:

- Code provisions are effective in reducing the damage mainly above lintel level. Brittle shear failure in wall piers still occurs but can be

Fig. 7 Partial collapse below lintel band

Fig. 8 Positive action of bands reduces damage sharply

reduced by providing an additional horizontal band, preferably at sill level. The vertical reinforcement at the corner of the model, in combination with horizontal bands increases the strength of the model as well as reduces cracking at corners.

- The provision of a seismic band at lintel level is the minimum requirement to prevent the collapse of the house in random rubble stone masonry models made in mud or cement sand mortar. The mere use of rich mortar without any other earthquake resistance measure is not adequate to prevent collapse of structures.
- The injection of cement grout in localized damaged areas can restore the original strength and stiffness. The scheme of repair involving stitching of corners of walls avoids delamination of walls during shock test.
- The external binding scheme of retrofitting is effective for increasing the strength beyond that of the original system, as cracks in the retrofitted models occur in new positions instead of the regions of previous cracks. The introduction of external horizontal tie bars helps reduce further cracking because of the ties of the walls behaving similarly as a band and are capable of resisting bending moment due to out-of-plane vibration of the wall. Moreover, external binding with welded wire mesh in damaged region not only increases the lateral resistance of the wall but also prevents shear and flexure failure of the models.
- The acceleration pattern along the height of the model generally shows that prior to cracking the acceleration at the top of the model is higher than that at the base but after cracking the acceleration at the top of the model is smaller than that at the base of the model. It is also observed that after cracking of the model the ratio of roof to base acceleration decreases in successive shocks for the same model. This indicates that the damaged lower portion of the model functioned as a kind of base-isolator that prevented the propagation of energy into the upper portion.

For a full copy of the paper, please contact the author at: panagfeq@iitr.ernet.in

Fig. 9 Unstrengthened house of cement-sand mortar

Fig. 10 Unstrengthened house constructed with mud mortar

A summary of the report, "Seismic vulnerability and strengthening of historic building, in Lalitpur, Nepal",

by Dr. D. D'Ayala, Dept. of Architecture and Civil Engineering, University of Bath, England.

Introduction

The report analyses the seismic vulnerability of local traditional building types, and provides guidelines for repair and seismic strengthening work in the City of Lalitpur and village of Khokana, Kingdom of Nepal.

The work entails:

- Identification of most common layouts, structures, and building massing
- Census of existing traditional seismic resilient features
- Selection of a number of buildings for each type in a particular area of the urban centre

For the selected sample the following is carried out:

- Development of a tailored survey form,
- Street survey aimed at identifying geometric and structural features,
- Analysis of the data to assess seismic vulnerability
- Definition of damage scenarios.

Repair and strengthening recommendations form the conclusions of the report.

Traditional construction features in ordinary buildings

The traditional *newari* house is usually of rectangular plan shape and over three storeys high. The depth of the plan is usually about six metres with façades of various widths but most commonly between 4 to 8 metres. The organisation of the house is usually vertical, over 3 storeys, with a spine wall running up the height, creating front and back rooms. At the upper storey the spine wall is sometimes replaced by a timber frame system so as to create a larger continuous space. The staircase is usually a single flight to one side of the plan. The typical inter-storey height is quite modest, between 2.20 and 2.50 m. The bathroom, where present, is found at ground floor, while the kitchen is on the top floor, usually directly under the roof. The first floor is traditionally used as bedrooms, while the second floor is used as living room and for visitors' reception.

Masonry types

The most common building material is brick bonded with mud mortar, forming ordinary masonry. There are typically two types of bricks: ordinary sun dried bricks of dimensions 210*105*50 mm, set in mud mortar, and vitrified fired bricks, with same dimensions but a trapezoidal cross section, so that the mud bed-joint is partially covered externally by the brick. This type of brick is usually used in better quality construction for the facing of external walls. Because of the vitrified surface and the overlapping over the joints, this wall construction is substantially impermeable to rain water.

The wall construction historically is of three solid brick leaves with courses of runners bonding the leaves together. Commonly the thickness of the walls at ground floor is about 450 mm reducing to 300 mm at the third floor. Another rather common form of construction is two leaves brickwork with rubble infill. The overall thickness is greater than for the previous case, and the two leaves are usually each made of double brickwork.

Floor and roof structure types

Traditional floor structures are made of timber joists running from wall to wall with dimensions 100*70 mm spaced closely at intervals of 150 to 200 mm. Above the joists there are usually planks or bamboo chirpat covered by compressed mud. A slightly less common solution is wooden joists with brick tiles and mud. The layout of the floor joists is usually normal to the façade, and it is quite common that an internal timber wall plate runs just above the windows from party wall to party wall. As a result, spandrels above windows are usually very shallow, just the height of 3 to 4 courses of bricks. In many cases joists come through to the external surface of the wall. Internally they rest either on an intermediate wall or, less commonly, on an internal timber frame called a *dalan*.

Among the many striking timber construction details of traditional buildings in the Kathmandu Valley, the *dalan* is certainly the most obvious and interesting in structural terms (Fig. 11)

The *dalan* is a timber frame made of columns, surmounted by capitals which bear double beams. The two adjacent timber frames are usually connected only at the level of the beam. The *dalan* is most commonly found at the ground floor of the main façade of buildings in which the front

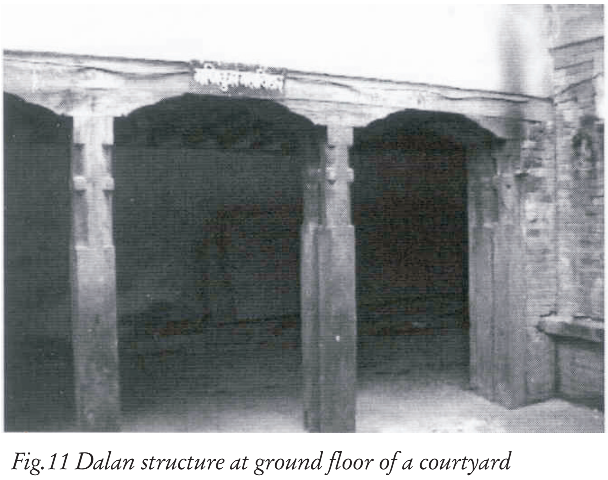


Fig.11 Dalan structure at ground floor of a courtyard

room is used as shop or workshop. It is also common in upper storeys as an internal structure in place of the spine wall. The columns usually have a square cross section of between 100*100 mm and 150*150 mm.

The *dalan* usually spans most of the width of the building with only small masonry piers of about 200 mm width restraining it laterally and connecting it to the rest of the masonry box.

In seismic terms the *dalan* is very weak for lateral loads, as all connections are simply pinned; the only lateral restraint, when present, is represented by the shear and bending strength of the masonry piers at the edge of the façade.

Window openings vary in size depending on the period of construction. The older buildings have generally smaller squared windows with lintels extending well into the surrounding masonry. These also are usually built with a double frame. The size of the windows within a storey may vary depending on the use of the room. Figs. 12 and 13 show different window layouts.

In more modern construction window lintels are made of flat brickwork arches, and, in a minority of cases, by stone frames. Traditionally, the openings are placed away from the façade's edges, leaving sufficient width for the lateral pier, constant throughout the height. This means that the pier can possess substantial in-plane shear stiffness, and in turn form a most effective connection with lateral walls.

Fig. 12 Different size of windows at same floor

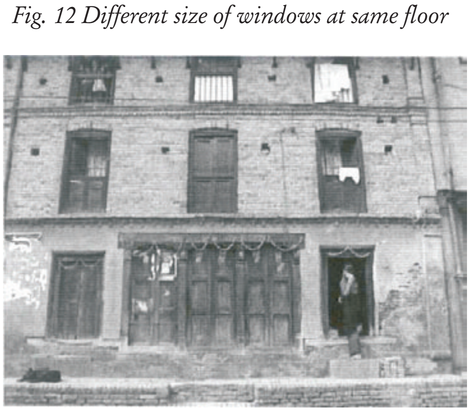


Fig. 13 Whole height windows

Another common feature of Nepalese traditional construction is the insertion of pegs, called *chokus*, to restrain floor joists from sliding over walls. Two vertical pegs are usually inserted through a joist on each side of the wall. Typically this will occur every two or three joists

An essential feature of the three-dimensional box-behaviour of a load bearing masonry building is the connection between orthogonal walls. Typical masonry construction usually presents a good level of connection when the four perimeter walls are built at once. However in urban areas, very often a plot in a block of houses can be built up at a later stage than the two adjacent to it resulting in poor connections. Most of the wall connections observed in this study were poor.

Failure mechanisms and vulnerability evaluation

A computer program, based on input from a detailed survey of each building predicts the ultimate lateral load factor (% of gravity acceleration g), which will trigger the onset of a specific failure mechanism (Fig. 14). It is possible to predict possible damage modes and levels of vulnerability for individual or groups of buildings in relation to expected levels of shaking at the site. It is also possible to analyse the reduction in vulnerability obtainable by introducing selected types of strengthening.

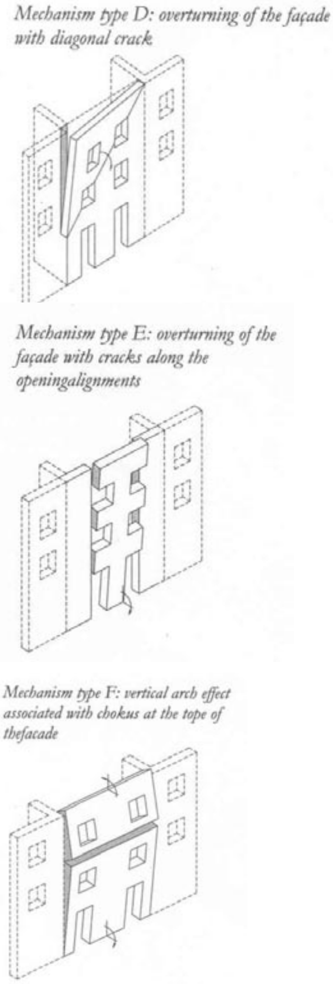


Fig. 14 A few of the many mechanisms considered in the vulnerability analysis

Summary of Findings

- Buildings with dalan are extremely vulnerable unless there is appropriate masonry restraint at the sides of the dalan structure. These façades need to be strengthened
- Façades with poor lateral connections and no visible presence of pegs are highly vulnerable, as they are prone to overturning over their whole height, causing the floor structure to collapse. The introduction of chokus at roof and possibly floor levels would consistently reduce the vulnerability from high to medium.
- Façades with basically good construction standards, such as good maintenance of the masonry accompanied by connection to party walls and presence of chokus at roof level, all show medium-low level of vulnerability.
- Well-built buildings will have high collapse load factors associated with global collapse mechanisms, typically in the range 0.40 to 0.60 a/g.

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New Publication
Protection of educational buildings against earthquakes: a manual for designers and builders, by NSET-Nepal and UNESCO

Educational buildings in Nepal face considerable earthquake damage as almost all buildings have not been built to be earthquake resistant. A preliminary survey conducted by NSET-Nepal on 700 buildings in 378 public schools in Kathmandu Valley showed that nearly all buildings don't comply with earthquake loading code requirements.

It is for these reasons that NSET-Nepal and UNESCO updated a manual first prepared by UNESCO, in 1987. The present manual is an improved version in the context of Nepal, and incorporates the experiences of earthquake-resistant design and retrofitting of school buildings

This manual takes into account prevalent construction practices in Nepal, and the use of local materials and labour. It also deals with the retrofitting and strengthening of old school buildings that can be undertaken by local masons under minimal supervision. Pertinent recommendations of the Nepal National Building Code (draft) have been taken into consideration while preparing it.

Although this manual is primarily meant for the technical persons engaged in the design, construction and protection of educational buildings against earthquakes, it is hoped that it will also help education policy makers, officials, community leaders and others to build earthquake-resistant houses and other buildings, even at the village level.

Several general chapters covering the effects of earthquakes on buildings are followed by the coverage of topics including:

- Site considerations
- Building forms for earthquake resistance
- Materials and quality of construction
- Masonry building using rectangular building units in cement mortar
- Low strength masonry in rectangular block and stone
- Detailing of RC frames
- Floor and roof construction
- Assessment of safety of masonry buildings
- Retrofitting of masonry building

Although set in the context of Nepal, this 63 page manual, plentifully illustrated (Fig. 15 for example) and attractively presented, is relevant to all other seismic areas with similar construction materials and methods.

Copies may be obtained from:
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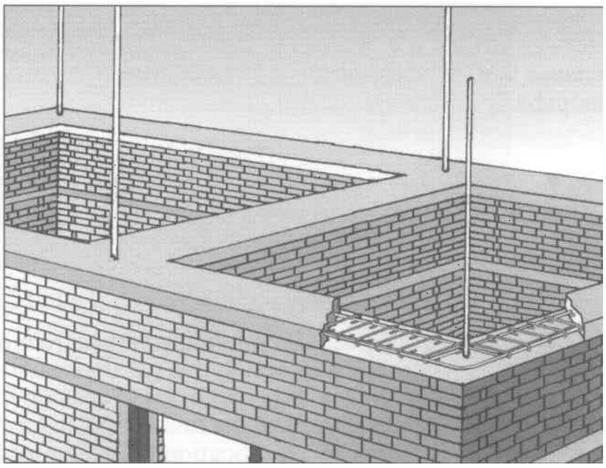

Fig. 15 Reinforced concrete band