Gujarat Relief Engineering Advice Team (GREAT)
GREAT Publication: June 2001

Repair and strengthening guide for earthquake damaged low-rise domestic buildings in Gujarat, India

A guide for:

- Self-build Owners
- Builders
- Local Engineers and Architects
- Local Authorities
- Relief Agencies

and other interested parties

by

UK Engineers with local knowledge:

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ISSUED FREE

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"GREAT" COMMITTEE MEMBERS

A group of UK qualified Professional Engineers from the Shree Kutch Leva Patel Community (SKLPC) in the UK have formed a working party, called the Gujarat Relief Engineering Advice Team (GREAT) to produce this Guide to Repair and Strengthen buildings damaged in this earthquake.

This Team comprises the following members:

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Without the support of these members, whose background and experience have been invaluable, this guide would not have been possible to produce.

Should anyone wish to contact the above people please direct all enquiries to web site: http://www.sklpconline.co.uk.

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DEDICATION

This Guide is dedicated to the memory of those who lost their lives and those that have been injured as a result of the Bhuj Earthquake of 26 January 2001.

Repair and strengthening guide for earthquake damaged low-rise domestic buildings in Gujarat, India

FOREWORD

The 21 January 2001 earthquake in Kutch, Gujarat has had a devastating affect on the area with many buildings damaged and large loss of life occurring. To date 20,000 people are known to have died and 167,000 people injured. This toll will increase as towns are cleared, an operation that will take many years.

We, a small group of professional engineers in the UK, have decided to help in some small way by bringing our expertise to help rebuild the local communities by producing this Guide. We visited the Kutch area following the earthquake. We are also familiar with local building practice as many of our families and relatives living abroad have close ties to the region.

The aim of this publication is to make the self-build owners, builders and local engineers aware of the effects of earthquakes on low-rise domestic buildings. These are identified as buildings of up to 2 storey plus attic, which are constructed of rubble masonry, cut-stone masonry and reinforced concrete frame structures. They are referred to as non-engineered buildings because often little or no engineering has gone into their design and they almost certainly have not been designed to resist earthquakes.

This Guide must also help local government bodies, relief agencies and other interested parties in Gujarat.

There is little published guidance on how to carry out proper repairs and strengthening of earthquake damaged buildings. Indian standards exist but are not used by local engineers or builders in urban or rural areas, mainly due to lack of knowledge and training. As a result, many of the owner-occupiers have unknowingly been carrying out bad repairs in Gujarat.

Many buildings have been severely weakened, and the authors are concerned that there could be another disaster in waiting from a future earthquake. Good repairs, using well-recognised seismic standards may reduce this vulnerability.

This Guide aims in simple terms to explain to the user why earthquakes happen in India, which regions are seismically active, how buildings respond in an earthquake; and how to safely carry out good repair and strengthening techniques to earthquake damaged buildings.

In order for this Guide to be produced acknowledgement is paid to Professor AS Arya’s book “Guidelines for earthquake resistant non-engineered construction”, produced in conjunction with the International Association For Earthquake Engineering, October 1986. Extracts from this publication have been used in this Guide. As highlighted in that book, we too are of the same opinion that the material given in this Guide should be readily available to people at various levels concerned with earthquake disaster through safe construction. For this purpose no royalty is to be paid and only due acknowledgement is to be given to this Guide. Hence, this Guide is intended for issue free of any charges, by sponsors who wish to print and distribute.

RESPONSIBILITY

The building owner is responsible for determining the need for the repair and its extent, whether it is practical and safe to carry out the repair and whether it is within his budget. It is advised that the building owner should in all cases seek professional advice from a qualified structural engineer before carrying out any repairs. It is also equally important to retain the services of a qualified builder when carrying out repairs. This Guide is intended to help in the repair process but where there is difficulty in interpretation the relevant Indian standards related to earthquake design and construction should always be used.

Since the writers of this Guide do not have any control over the inspection of and diagnosis of damage and the design/control of the repair, they are not liable for any acts or omissions. They cannot be liable for any loss or damage occurring consequent to the use or misuse of this Guide.

This Guide does not replace any rules, regulations and codes of practice in force.

Some of the illustrations used in this Guide have been reproduced from a variety of sources. Efforts have been made to contact any copyright sources where this is possible.

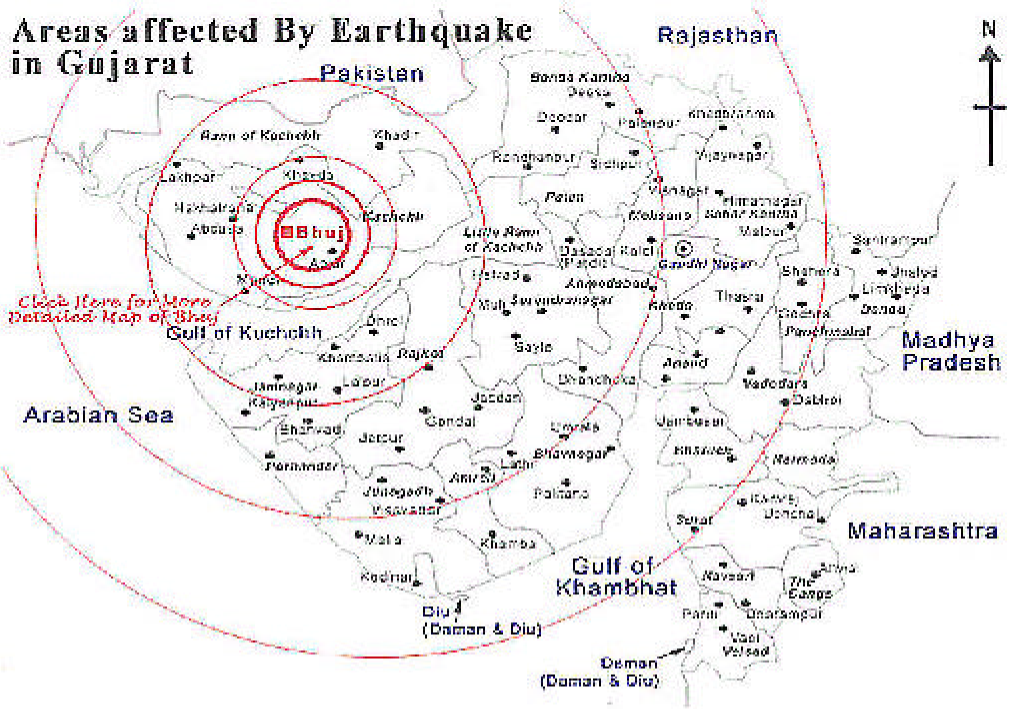
THE BHUJ EARTHQUAKE –26 JANUARY 2001

The Bhuj earthquake in Gujarat, India occurred on the 26 January 2001 and caused massive destruction to property and loss of life. This earthquake had a moment magnitude Mw = 7.9 USGS and struck the Kutch region of India at 8.46am local time, with the shaking lasting for a few minutes. Kutch has a population of about 1.3 million people. Other major cities in Gujarat eg Ahmedabad and Jamnagar, which are hundreds of kilometres away, were also effected by the earthquake.

In Kutch, major towns such as Bhuj (pop 150,000), Anjar (pop 50,000), Bhachau (pop 40,000), and Rapar (pop 25,000) were almost totally destroyed and many villages surrounding these towns were badly damaged. To date over 20,000 persons are reported dead and over 167,000 injured, predominantly from the Kutch region. The reported deaths will increase as towns are cleared, an operation which will take many years.

Most people were killed or badly injured because of:

a) poorly constructed buildings either totally or partially collapsing
b) walls collapsing within narrow streets, burying people escaping into them
c) untied roofs and cantilevers falling onto people
d) free standing high boundary walls, parapets and balconies falling due to the severe shaking
e) gable walls falling over
f) the failure of modern reinforced structures with large open spaces at ground to first floor level, for example garage or shop spaces, collapsing and burying occupants (soft storey collapses)
g) inhabitants not knowing how to respond to the shaking and collapse of walls around them.



1 INTRODUCTION

This Guide is written by UK based Gujariti engineers who are professionally concerned that repairs and strengthening works on low rise domestic buildings damaged by the Bhuj earthquake are not being carried out properly, nor employing some of the Indian and other international standards that describe how non-engineered buildings can be made more earthquake resistant. This Guide is produced to help owners and builders, as well as other interested parties. The Guide is specific to Kutch but may also be relevant to other parts of Gujarat or India where similar forms of materials and construction technology are used.

The authors of this Guide are UK practising structural and geotechnical engineers who wish to help the local community because many Gujartees in the UK originate from the earthquake area and still have close family ties to the region. Other members of the team have international experience in earthquakes that have occurred during the last two decades.

Damage to buildings were caused by a combination of affects:

- Old decaying buildings predating modern construction practices
- New Buildings not being designed to Indian earthquake codes
- Lack of knowledge, understanding or training in the use of these codes by local engineers
- Unawareness that Gujarat is a highly seismic region
- Buildings erected without owners seeking proper engineering advice
- Improper detailing of masonry and reinforced structures
- Poor materials, construction and workmanship used, particularly in commercial buildings
- Alterations and extensions being carried out without proper regard for effects on structure during an earthquake
- Buildings having poor quality foundations or foundations built on poor soils
- Little or no regularity authority administering or policing the codes

Generally, commercial buildings were worst affected by the earthquake because of poor workmanship, use of materials and inadequate attention to detailing.

Low-rise rubble masonry buildings were totally destroyed near to the epicentre, but some survived (though badly damaged) when further away. These were also older forms of construction. Cut-stone masonry and more modern reinforced concrete framed buildings faired much better, although damaged to varying extents. These later building types are largely built by owner-occupiers and hence better care was taken in the materials used and their workmanship. Many lessons can be learnt from those non-engineered low rise buildings which survived.

The vast majority of owner-builders are also the ones who have spent their life savings in constructing their homes, and who wish to ensure their homes are properly repaired to resist a possible future earthquake, but who are unable to always obtain proper advice. This Guide is intended to help those people. These are also the most in need of this advice, as they carry no home insurance.

Even though this Guide provides lots of advice on how to repair and strengthen buildings, each building will respond uniquely in an earthquake, and therefore it is difficult to generalise in a Guide such as this. Therefore, it is important for the property owner to seek professional advice from an experienced structural engineer and builder to check whether repairs can be carried out. Also, any repairs must always consider the safety of the people involved.

Large earthquakes can still cause damage to buildings even if designed to the relevant Indian codes and this Guide. However, the seismic measures taken are intended to absorb damage in a controllable way and save lives. They are not intended to ensure that a building always survives intact. If seismic measures had been taken into account in the design of buildings the loss to life would have been significantly reduced as many buildings would have not collapsed.

2 PURPOSE OF GUIDE

2.1 The Potential End User

This Guide is primarily aimed at the owner-occupier or builder who wishes to carry out proper repairs to his damaged building to improve its safety. At the same time he may wish to carry out strengthening works to make the structure more seismically resistant, in which case this Guide will also assist him. It will also serve as a useful reference document for the local engineer and other interested parties for new low-rise buildings, defined as up to 2 storey structures plus roof.

The illustrations for the repairs and strengthening works to random and cut stone masonry walls and reinforced concrete damaged buildings given in this Guide, have taken information from mainly Indian Standards on design and construction for seismic resistance structures and from many other published papers and textbooks. These structural building types are very common in Kutch, Gujarat. Since there are about six different seismic Indian standards this Guide introduces into one document some of the main repair and strengthening methods. However, a technical reader is recommended that he should also consult these standards. The owner or builder may not have ready access to these standards hence, why this Guide may be a useful source of reference. It does not replace the Indian standards or codes or other regulations in place.

The references used in producing this Guide are given at the end of this booklet.

2.2 What the Guide is not

This Guide does not address repair and strengthening works to:

a) earthen and adobe type buildings
b) wooden structures
c) very weakly bonded or poorly constructed rubble masonry construction which have been severely damaged beyond repair
d) precast concrete and brick buildings.

For these building types, the user is recommended to consult the Indian standards and the IAEE (1986), "Guidance for earthquake resistant non-engineered construction", and to obtain the opinion of a qualified structural engineer.

2.2 History of Earthquakes, Seismology and Geology

Those who are interested in understanding why Kutch and parts of Gujarat are in the worst effected earthquake zones in India, can read Annex 1 of this Guide.

2.3 Structural Performance of buildings during an earthquake

Similarly, a section of the population (eg local engineers) may be interested in the structural response of buildings during an earthquake and this is described in Annex 2 of this Guide.

2.4 Good Practice notes on new build

Some advice is also given to those wishing to build up to 2-3 storey homes to resistance future earthquakes, see Appendix D.

3 TYPES OF OBSERVED DAMAGE IN KUTCH

3.1 Non-Engineered rubble masonry buildings

Many buildings in Kutch of up to 2 storeys in height are made of random rubble masonry construction. The 26 January 2001 earthquake caused massive damage to these buildings. A great many partially or completely collapsed, especially close to the epicentre in Bhuj, Anjar, Bachau and Sukhpur, where the destruction was almost total. Towns and villages that are further from the epicentre of the earthquake were less affected but only in the sense that total collapse was not as widespread. For example, near the villages of Kera or Naranpur buildings of this nature were still standing with sometimes only partial collapse.

During the earthquake, many buildings easily separated at corners and T-junctions resulting in walls overturning and roofs collapsing, which killed thousands of people. This was because the random rubble walls were made of uneven stone and the stones were laid on either weak soil or mortar bedding. Under the heavy seismic shaking, the tensile strength of the mortar (and rubble) was easily exceeded, and walls bulged or totally collapsed.

In addition many of these buildings had timber or heavy stone slab roofs that were not properly tied to the top of the walls and the walls then came apart causing the roof to cave in. The buildings are also poorly founded with stone footings nominally below the ground surface on weak loose soils. This is particularly so across the Bhuj plain as the surface is often covered by an alluvial fan from the surrounding mountains where streams flow during the rainy periods. It is likely that many failed by loss of support from the ground as a result of bearing failure on the loose sands or by excessive settlement.

Even single storey buildings suffered severe damage and/or partial or complete collapse. Figure 3.1 and 3.2 shows some of the failure of these buildings.

As Kutch is in the highest seismic zones, new buildings should not be made from random masonry walls, if affordable, as they are incapable of resisting the severe shaking.

Figure 3.1- Collapse of random masonry building in Manukawa

Figure 3.2 – Partial collapse of gable wall for a single storey random masonry wall in Kera

Figure 3.3 – Heavily damaged single storey rubble masonry wall with concrete roof in Manukawa & Sukhpur.
Note:
Walls survived due to diaphragm action from roof. Cantilever beams embedded in walls also helped this. Note window openings are also not close to corners.

3.2 NON-ENGINEERED CUT-STONE MASONARY WALL BUILDINGS

3.2.1 General

Generally, cut-stone and concrete blockwork buildings are built with more care and attention than rubble masonry structures but again were not seismically designed. Older buildings had timber floors and roof, while newer construction have concrete floors with a flat concrete roof or a clay tiled timber roof. Many were damaged but did not collapse. Damage varied from slight to heavy damage.

The masonry buildings which performed the best, have the following features in common:

- Cut-stones were bedded in cement mortar
- Roofs were properly fixed to the top of the walls.
- Window openings were sensibly sized in relation to the total wall length;
- Buildings were symmetrical with no concentrated masses;
- Many had cross walls at sensible spacing, although it was unclear whether they were adequately tied at T and L junctions;
- Foundations were typically founded at 0.5 to 1.0m depth, probably on firm to medium dense soils or rock.

3.2.2 Old masonry building built with thick cut-stones

An old government building (predating 1900's) made with solid cut stone masonry walls is shown in Figure 3.4. This building received slight to moderate damage although it is in the centre of Bhuj and all around, rubble buildings have totally collapsed. The floors and roof are of timber and an adjacent similar building had cut-stone walls which were at least 0.5m thick. The upper storey wall is seen to be damaged at the edges by bending cracks caused by out-of-plane shear forces. Untied architectural stonework has also fallen off at roof level, as might be expected from severe shaking. The heavy wall units and regular stone blocks prevented collapse of these old buildings.

Figure 3.4 Cut-stone building in Bhuj

3.2.3 Window openings

Figure 3.5 shows a two-storey modern cut-stone wall building near Bhuj, in town called Mirzapur. The building has cut-stone walls about 0.225 to 0.3m thick and has a 1st level concrete floor and a pitched timber roof. The window openings are not close to the edge and are also sensibly spaced. This is probably one of the main reasons why it survived with so little damage. Even so some vertical bending cracking has happened near to the corners, again due to out of plane shear forces.

Many buildings which did not collapse suffered from severe diagonal cracking at their corners, some with partial collapse at corners, primarily because of window openings being too close to the corner and because of lack of toothing between returns.

Figure 3.5 Modern cut-stone masonry building in Mirzapur

3.2.4 Peripheral seismic bands or ties

Seismic bands or ties greatly increase the strength of buildings in earthquakes. The railway lookout building in Figure 3.6 is made with random masonry, is well-constructed and is bonded with cement mortar and suffered very little damage. What sets this building apart from others that collapsed nearby, is that it has been designed with strong reinforced concrete seismic bands at lintel and cill level, which completely tie the four walls. There is also a flat concrete roof. The seismic shear force is resisted by the lintel and cill bands, and has clearly strengthened the building against repeated shaking from an earthquake which would make lesser buildings collapse.

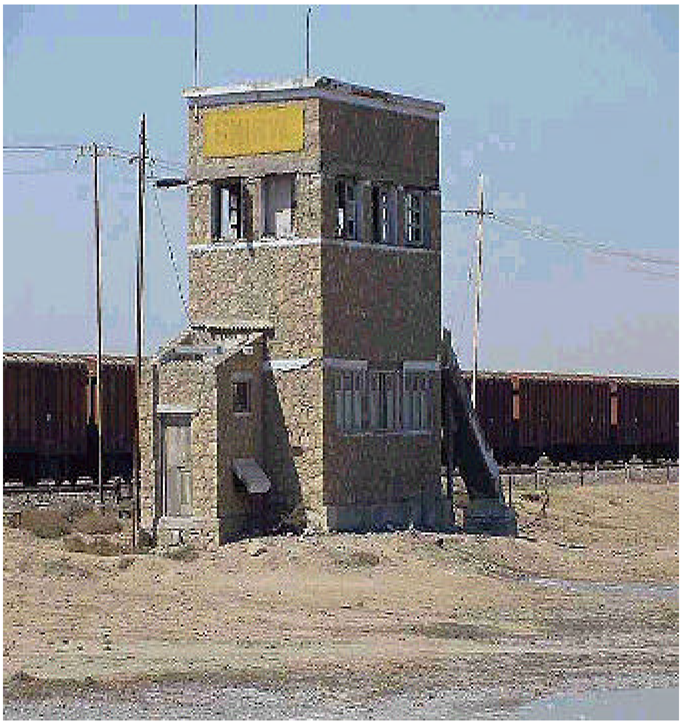


Figure 3.6: Strengthening of buildings by use of seismic bands

3.2.5 Typical foundations of masonry buildings

In villages radiating to the southwest and southeast of Bhuj, Kutch, many masonry cut-stone buildings have the following foundation details:

(1) Stepped walls which rise from a weakly cemented broken rock filled trench strip; or
(2) Walls that are cast off a concrete strip footing, lightly reinforced.

The foundations of newer type buildings are typically about 0.5 to 1.0m depths below ground.

Where the inland soils are sedimentary sands and rock little or no damage to these foundations were observed as the ground conditions were good. However, towards Anjar and to the coastal regions of Kutch or the lower areas of the Rann, for instance, many buildings failed because they were founded on soft clay or loose sand which was saturated by groundwater. Many buildings failed when the ground liquefied, the loose water-filled sands turning to a quicksand during the earthquake.

3.3 NON-ENGINEERED REINFORCED CONCRETE BUILDINGS

3.3.1 General

In the last 10 to 15 years reinforced concrete frame structures have become a common construction feature of domestic buildings in Kutch. These are usually frames of concrete column and slab construction with either a flat concrete roof or a pitched timber roof to keep the interior of the building cool in the summer. They are usually up to 2 to 3 storeys in height. These buildings were designed to support the vertical weight of the structure. The majority were damaged in the earthquake because they were not designed to resist horizontal forces caused by seismic loading.

Often, the owner retained an local architect and sometimes a local structural engineer’s practice to design the building. Even so, no buildings were designed for seismic shaking. If it were not for buildings having “non-structural” infill wall panels many more buildings might have experienced total collapse. Seismic shear force and deformations would have been concentrated at the column heads, causing soft storey failures as occurred in many multi-storey structures with large openings at ground level.

3.3.2 Building Configuration and Soft Storey Collapse

Some domestic reinforced concrete buildings had large internal openings or unsymmetrical masses at first or ground floor level. This caused severe structural damage and even collapse. Figure 3.7a shows a building, which collapsed because part of the floor area was converted to an opening for car parking. The building was subjected to torsion about its centre of rigidity and failed because of soft storey behaviour with large deformations and rotations concentrated at the top of the columns (Fig 3.7b).

Fig 3.7b The inset shows large deformations were concentrated at column heads, which caused many soft storey failures, as per picture. Buildings if designed with uniform deflections as per left diagram of insert would have survived without collapse.

Figure 3.7a – Typical soft storey and torsion collapse in Bhuj

Figure 3.8 shows a building where the owner had a middle floor supported on columns with large internal open spaces, and hardly any masonry infill walls. Under seismic loading, large deformations occurred at the top and bottom of the columns and a soft storey collapse occurred, the upper floor storey falling onto the first storey. This shows that soft storey collapses do not always occur at ground floor.


Figure 3.8 – Soft storey second floor collapse in Sukhpur

3.3.3 Non-Engineered infill walls acting as shear walls

Many buildings were prevented from collapse by the presence of “non-structural” infill wall panels which acted as **shear walls** despite not being designed for this purpose. No buildings were designed as moment resisting concrete frames to resist cyclic shear and bending moments at column and beam connections.

The infill walls were mainly made of cut-stone masonry or concrete block. Reinforced concrete walls were not used. Buildings survived collapse because these infill walls took the brunt of the lateral shaking. They were most effective when the construction procedure involved a high degree of bonding between the wall and column. This was often achieved during the construction, by building the walls up to first floor level leaving a gap at column positions, then casting the columns using the walls as shutters. Minimum wall sizes were about 220mm thick for blockwork.

Figure 3.9 shows the effectiveness of shear walls in preventing an RC framed building from collapse. This building experienced severe shaking causing moderate to heavy damage to the infill panels, but this prevented column failure. Many infill panels in these types of buildings will need to be restored following the earthquake. It should be noted that this wall was effective despite being compromised by the presence of a door opening.

Figure 3.9 Infill panels to an reinforced concrete frame building acting as non-structural shear walls, provided stability to the overall frame – Bharasar

Figure 3.10 Infill panels again prevented collapse of this structure although all the roof tiles fell off - Mirzapur.

3.3.4 Window openings in infill panels

Large window and door openings severely undermined the ability of infill panels to act as non-structural shear walls. These openings were placed too close to the corner columns of the building. Lintels were placed over the openings but did not extend over the length of the wall as is recommended for seismic design. Consequently, wall panels experienced diagonal shear cracking which extended from the openings to the top and bottom of the solid walls, sometimes causing diagonal cracking of columns when no resistance was afforded by the wall, see Annex 2.

Generally, the greatest damage occurred at ground floor level. Upper storeys survived with surprising little damage (slight).

Sometimes older RC buildings, modernised by adding an extra floor, suffered greater damage as columns were not properly connected to the original concrete frame and the structural mass was altered by adding this floor.

3.3.5 Crushing of column head and bases

When masonry infill walls were ineffective because of large openings, column heads were subjected to large vertical and lateral seismic forces. The heavy eccentric compressive stresses crushed column heads and large shear deformations caused concrete to spall away from the main bars because of links being to far apart. The extent of damage to the column heads often depended on how well the infill wall panels were bonded to the columns. Figures 3.11 and 3.12 give examples of this.

Figure 3.11: Heavy compressive stresses with large deformations causing total destruction of column head with heavily bent main bars. Concrete not contained by links because they were to far apart.

Figure 3.12 A column that survived with minimal distortion as infill walls performed well and repairs being carried out to damaged column head showing minimal distortion to main bars (right)

Some common problems, which resulted in severe damage to the column heads or bases, were from poor detailing as follows:

(1) Drain pipes and other services placed inside columns, caused severe weakening of the columns making it less resistant to lateral loading;

(2) Shear link spacing was too large (typically 200-300mm), thus not providing adequate confinement to the main bars, causing concrete to fall out;

(3) Links were not bent backwards into the columns so they easily separated, again letting concrete out of the main bars;

(4) Very small links (6mm diameter) were used;

(5) Main bars were not bent back into the floor or ground beams so that reversal of shear loads could not be resisted by the beam and column connections. Many failures occurred at beam/column junctions, see Figure 3.13.

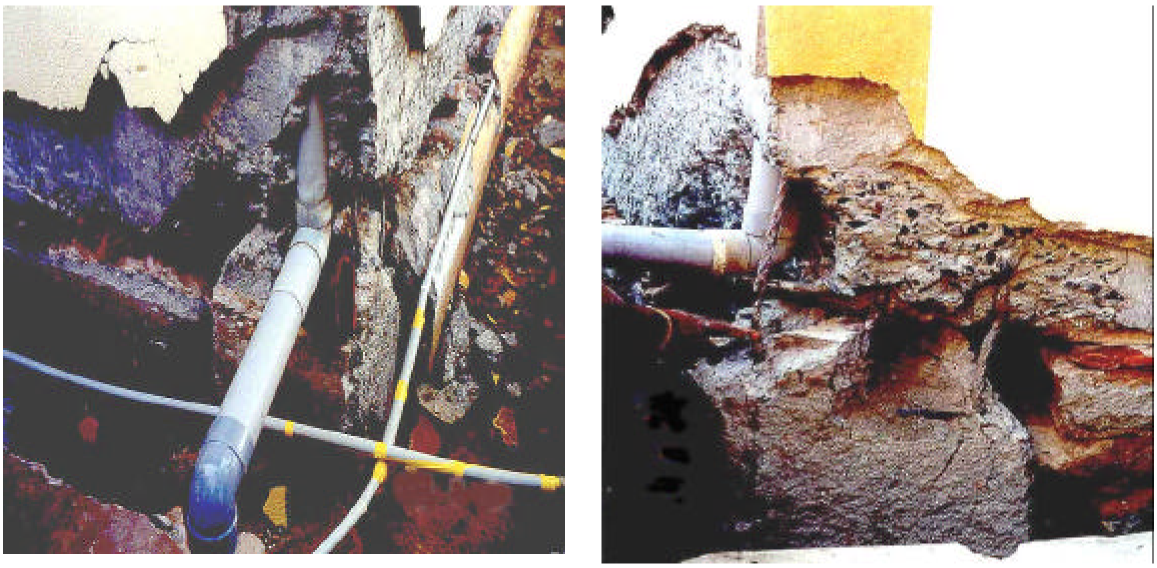


Figure 3.13: Separation of ground beam and column junctions caused by concrete crushing in Sukhpur. Damage made worse by the weakening presence of a plastic pipe within the column.

3.3.6 Roof failures

Damage to flat roofs was rare. However, pitched roofs often experienced non-structural damage by tiles falling through open space between the timber battens as no tiles were nailed into the timbers. Many tiles were manufactured with no holes to allow them to be nailed to the roof.

3.3.7 Canopy structures

Several modern buildings had a single storey canopy with a flat roof supported by columns at one end and beams running into the main structural frame at the other end. These suffered varying degrees of damage depending on how slim the columns were, see Fig 3.14.

Beam Fracture

Snapped Column

Fig 3.14 Collapse of a canopy structure due to column failure

3.3.8 Underground water tanks and storage containers at roof level

Many modern buildings have large concrete water tanks with bases about 2 to 3m depth below ground. This stores the water, which is regularly pumped to much smaller header tanks at roof level. The tanks appeared to survive the earthquake with little or no damage. However, tanks lined with masonry walls are said to be damaged.

Smaller storage containers built on top of the roofs were either located directly on flat roofs or on short columns. These either slid along the roof breaking water pipes or sometimes toppled over when the short columns fractured. There was no evidence that the smaller header tanks were responsible for structural failure of 2 storey domestic houses.

Figure 3.15 Flat roofs with small water storage containers - Madhapur

3.3.9 Typical foundations of reinforced concrete frame buildings

Typically foundations for these structures are pad footings founded at 1 to 2m below ground. The footings are not usually tied but often have a ground beam located just below plinth level. In the area around Bhuj the footings are founded on weakly cemented sandstone layers, medium dense sand or rock. The infill masonry walls below ground are generally built off a shallower depth coming up to the underside of a ground beam. Walls are then continued above the ground beam.

Few failures of foundations were observed outside areas of liquefiable soils. When failure occurred at column and ground beam junctions, infill walls also failed. Structures with this mode of failure will need temporary foundations to support the main structure before carrying out permanent repairs.

There were however many examples of poor detailing to columns, ground beams and foundations. Figure 3.16 show one example of poor detailing of column to base, with typical link spacings over 250mm to a very slender column.

Figure 3.16 Poor reinforcement detailing for an Reinforced Concrete frame building about to be constructed in Sukhpur

3.3.10 Example of a 3-Storey reinforced concrete frame structure, which is severely damaged in Kundanpur (near Kera) Kutch

An example of a recently completed reinforced concrete frame building with blockwork masonry infill walls which was severely damage, caused by a catalogue of poor design practices is described below (see also Figures 3.17 to 3.21). The owner of this property had retained the service of a local engineer to design his building.

a) **Poor building configuration (resulting in torsion during earthquakes).** The ground floor plan was asymmetrical (L-shaped internally) relative to the floors above. As a result, the whole building at ground floor level has twisted clockwise under the heavy mass from the floors above. Severe damage has occurred to the walls and columns at ground floor level, see Figure 3.17. The reason for the L shape plan at ground level was because the owner wanted a large open plan living room area.

b) **Discontinuous columns.** Figure 3.18 shows that the external columns along the wall are not continuous with the columns at first floor level and above. Only the corner columns are continuous through all the floors. This was a building where the owner decided during construction that the engineer had not allowed enough columns and he decided to place a few more between the walls. Unfortunately, they were placed randomly along the walls as shown.

c) **Large window openings.** Figure 3.18 also shows that the window openings between columns are large, exceeding the limit of 33% of total wall length as advised by the Indian codes for a three storey plus roof structure. The ability of the masonry blockwork walls to resist shear is thus diminished due to lack of continuity. Diagonal cracking has occurred through the masonry wall and columns. Other photos show that the bond between the columns and walls was very good because the walls were erected first and then columns cast afterwards, the walls being used as shutters. This probably prevented collapse of the building even though the columns were damaged.

d) **Short column failures.** Short column failure (diagonal cracking) can be seen to have occurred over the mid height of all the external concrete columns (these were 225mm square) and through the masonry columns. This is because when infill walls with wide openings are attached to columns, the portion of column that will deform under lateral seismic loading becomes very short compared to its normal height. Such short columns become much stiffer and attract much larger shear forces resulting in severe diagonal tension and cracking failure in the columns. This failure is plainly seen in Figs 3.19 and 3.20. The problem was magnified because plastic service conduits ran inside some of the corner columns and walls, reducing the column stiffness.

Under the action of the seismic shear and torsional effects, the damage to this building was largely concentrated at ground floor level with upper floors remaining intact and undamaged. The first floor concrete slab and beams were undamaged by the earthquake.

The foundation plans show walls were on concrete strip foundations, 0.75m wide, founded at a depth of 0.9m below ground. The external canopy columns were on 1.2m square pad foundations located at the same depth. The building was founded on a mixture of weak weathered sandstone rock at one end and medium dense to dense sand at the other end. The owner stated that the foundations had not failed. Photos and videos examined by the authors confirmed this was correct. There was no evidence of the structure experiencing significant total and differential settlement.

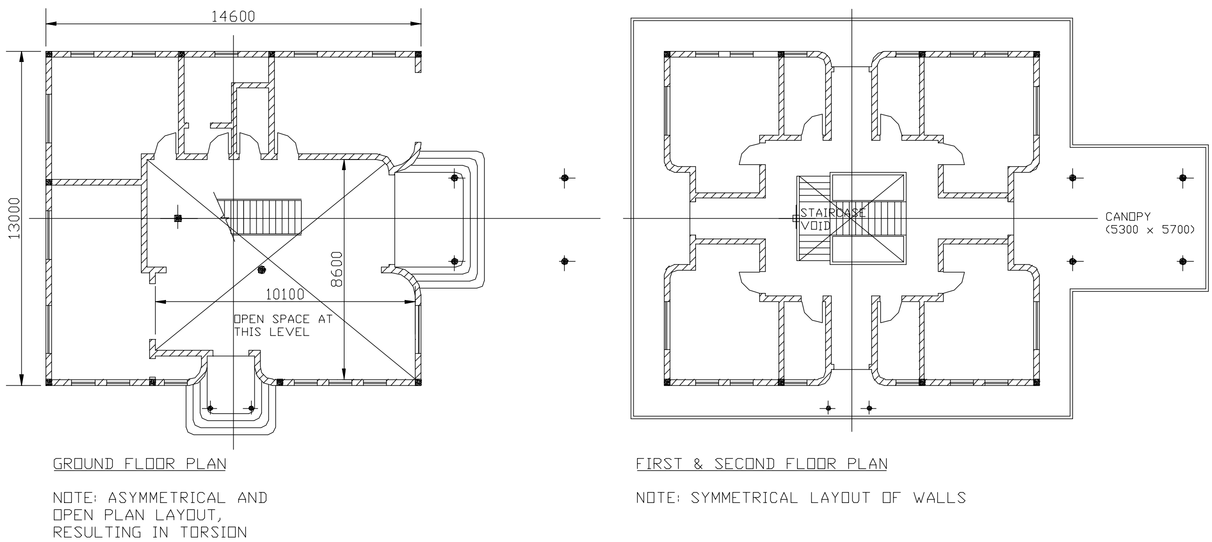


Figure 3. 17 Floor plans

Figure 3.18 Building under construction one year prior to earthquake

Figure 3.19 Damage to completed building after earthquake

Figure 3.20 Large window openings close to corners and short column failures

Figure 3.21 Diagonal cracking at corner column caused by twisting of frame and short column failure.

4 REPAIRS AND STRENGTHENING GUIDE

The authors suggest that Government and other local relief organisations provide grants as an incentive for the public to adopt earthquake resistant repairs and strengthening of damaged buildings and properly constructed new build. There is a genuine lack of awareness and necessary skills for improved construction. This Guide is intended to help in this process. It should also be noted that there are also excellent Indian codes/standards and the IAEE (1986): Guidelines for earthquake resistant non-engineered construction, should also be consulted. These should be on the reference shelves of all libraries and consulting practices in Gujarat.

We have tried to take the best from these codes and guidelines and to tune the repair and strengthening works to the more common types of 2 storey buildings, which apply to Kutch.

4.1 Definitions

Repairs – *actions taken to damaged buildings, which are intended to restore the structural strength lost in an earthquake, to the original level.* Such structural repairs involve actions such as rebuilding of cracked wall elements, stitching of walls across cracks by using steel reinforcement on wall faces and covered by cement mortar, or grouting of cracks using cement or epoxy like adhesive materials which are stronger than mortar and have tensile capacity. Non-structural repairs would also be included in this category.

Seismic Strengthening (retrofitting) – *actions taken to upgrade the seismic resistance of an existing building so that it becomes safer under future earthquakes.* This can be in the form of providing seismic bands, eliminating sources of weakness or concentrations of large mass and openings in walls, adding shear walls or strong column points in walls, bracing roofs and floors to be able to act as horizontal diaphragms, adequately connecting roofs to walls and columns and also connecting between walls and foundations.

4.2 Cost of seismic protection

It is much cheaper to design a building for earthquake resistance in the first place than to carry out repairs and strengthening works. Studies have shown that a building designed for seismic resistance is about 10% more expensive than one without. However, repairs to a non-engineered building may involve as much as 2 to 3 times the initial cost of introducing seismic features into a building. If repairs and strengthening has to be carried out, this could even be 4 to 8 times as expensive (Arya, 2000).

4.3 Assessment of building damage before carrying out repairs or strengthening

Before commencing any repairs it is important to

- Determine the materials which have been used in the damaged building
- Carry out a detailed foundation check;
- Carry out a detailed structural assessment of the damaged building with particular attention to vulnerable elements of the structure.

This should be assessed by a qualified structural engineer. It should be noted that both non-structural and structural repairs might be required to a building. The priority repairs should be to the structural components before embarking on any non- structural repairs (cracked slabs, falling plaster from walls and ceilings, rebuilding of parapets etc).

There is absolutely no point carrying out repairs to a building if the foundations have failed or the ground can no longer support the damaged building. Repairs to damaged foundations can be costly and difficult to instigate and hence a fine line may exist between demolishing the building or continuing with the repair.

Earthquakes may also cause failure of soft or loose ground whilst hillsides or sloping ground may become unstable. Whole towns and villages may be affected and although a building may appear safe for repair, near the foot of the slope or on it, further slope failures could be triggered by relatively small aftershocks or another future earthquake. Buildings in such terrain will require specialist advice of the stability of the whole area. No repairs to buildings should take place until this advice has been obtained. Elsewhere in the World, it should be noted that whole towns have had to be relocated to a stable area after an earthquake before a rebuilding programme can start.

The Building Damage Assessment Form and classification of damage (to recognised standards) is given in Appendix E. This is intended to provide more details in assessing damage to buildings.

4.4 Building types requiring repairs and strengthening

Illustrations showing how repairs and strengthening works should be carried out is given in various appendices listed below:

1) Appendix A - Repairs to random (rubble) masonry buildings
2) Appendix B - Repairs to masonry cut stone buildings
3) Appendix C - Repairs to reinforced concrete framed buildings

In some of the appendices a number of options are presented. Choice of repair method will depend on ease of repair, physical constraints and degree of damage.

The figures enclosed in the appendices are intended for use as follows:

- The owner-builder can identify a particular repair type and use the figure to suit his repair.
- In certain cases the repair types are accompanied with good practice notes for use with the figure(s).

Where the required repair is difficult to decide, the relevant Indian standards on design and construction practice should always be used with professional advice being sought from a structural engineer.

4.5 Guidance notes for new buildings

Although this Guide concentrates on providing good repairs and strengthening works to non-engineered structures, it was considered that some guidance may be useful on new buildings. For this purpose, Appendix E: Table E1 provides some useful tips for the design and construction of cut-stone or blockwork masonry stone buildings no higher than 2 storey plus roof. Similarly, Table E2 provides a note for reinforced concrete buildings of the same height.

However, all new buildings must be designed by a structural engineer, with knowledge of earthquake resistance design to the relevant Indian and/or American UBC: 1988 codes.

4.6 Some guidance on allowable bearing pressures for shallow foundations

Guidance on this is given in Annex 3 attached.

5 ACKNOWLEDGEMENTS

The graphics produced in Appendix A to C have been produced by architects, graphic designers and engineers working for Arup Associates. Thanks go to Kenny Fraser, Nik Browning, Ian Hazard and John T Roberts. Many thanks also go to Andy Thompson and Mike Oldham.

APPENDICES

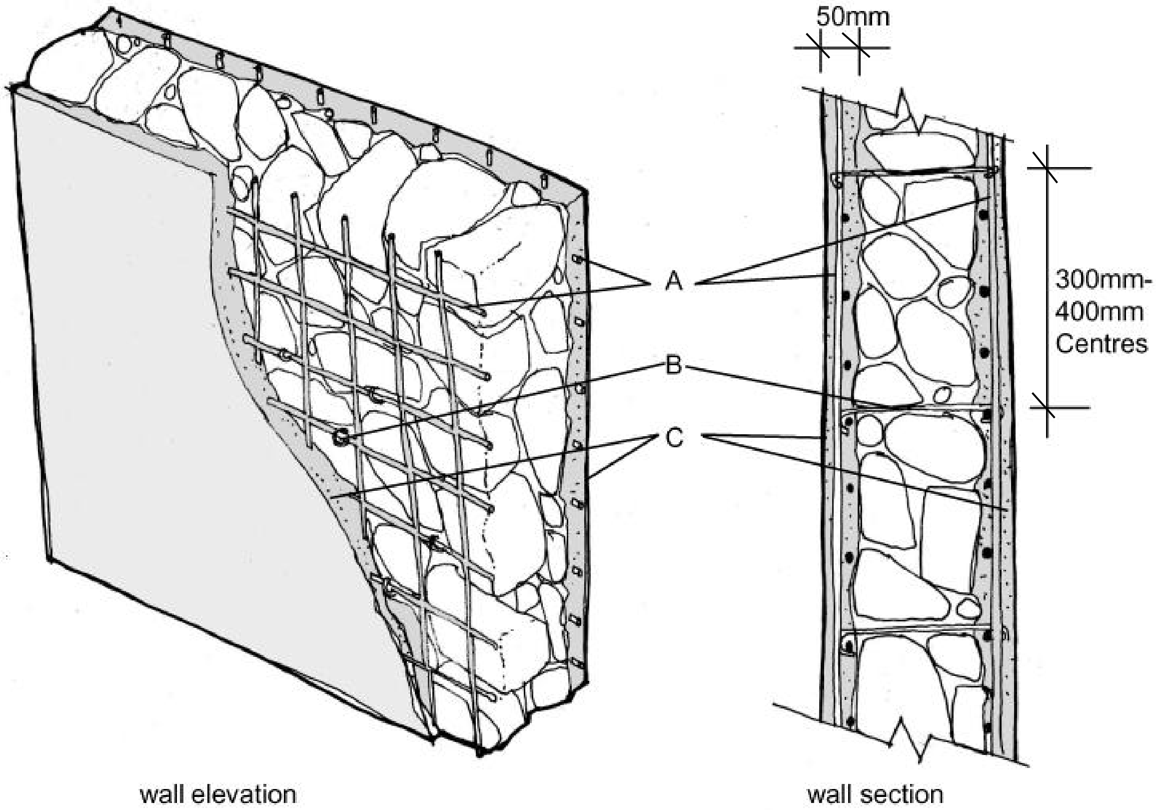
Note:
Some of the Illustrations presented in Appendix A, B and C have been obtained from References 2,3,7 and 9

APPENDIX A:
Repairs and Strengthening of Rubble Masonry Wall Buildings with Timber floor and roof

Note:

Some of the Illustrations presented in Appendix A have been obtained from References 2,3,7 and 9

A – Using wire mesh/light reinforcement



KEY POINTS;
A) Galvanized steel wire mesh (minimum 2mm diameter). Minimum laps to be 300mm
B) Tied together with steel through rods through the wall, at 300 – 400mm centres
C) Two coat cement/sand render 25mm to 50mm thick
D) Cut away loose material to sound wall

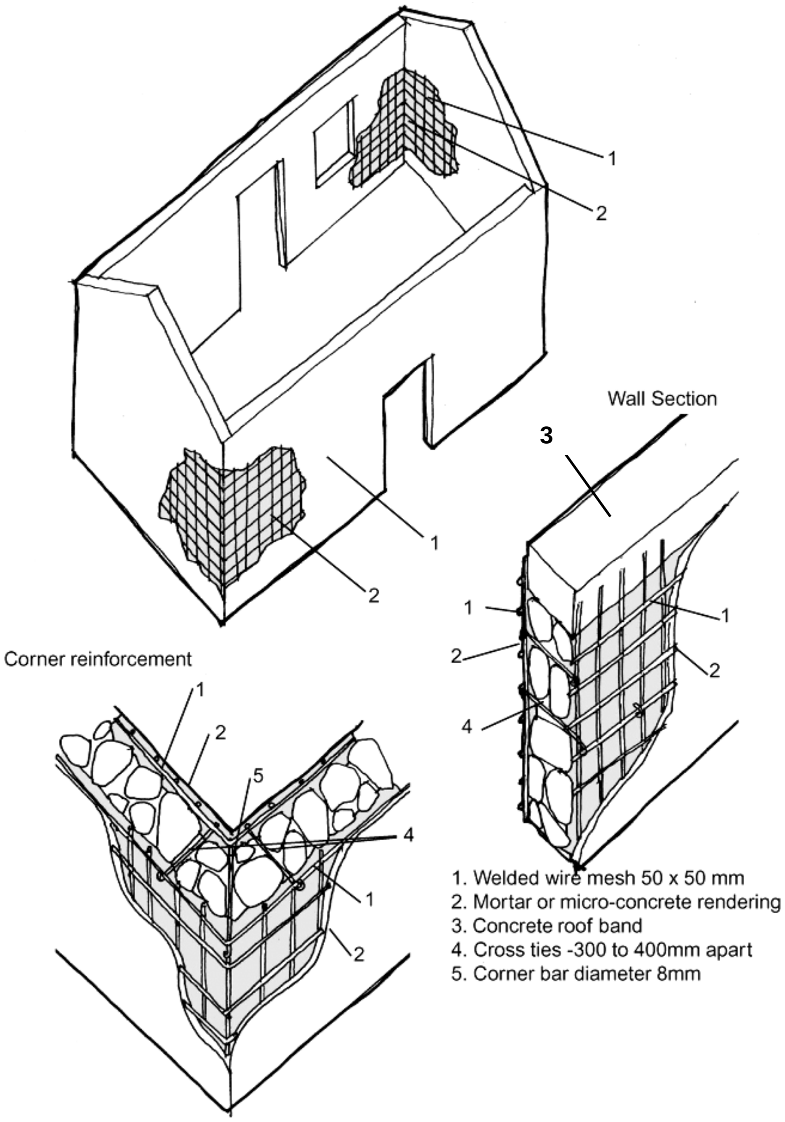
REASONS FOR USE AND COMMENTS

- Simplest form of repair to improve shear response and vertical load transfer capacity.
- Improves binding of stones.
- Wall to be cleaned and free of dust

This detail is also applicable to masonry cut – stone or blockwork walls

REPAIRS AND STRENGTHENING:	RUBBLE MASONRY WALLS **Figure A1**

A – Using wire mesh/light reinforcement



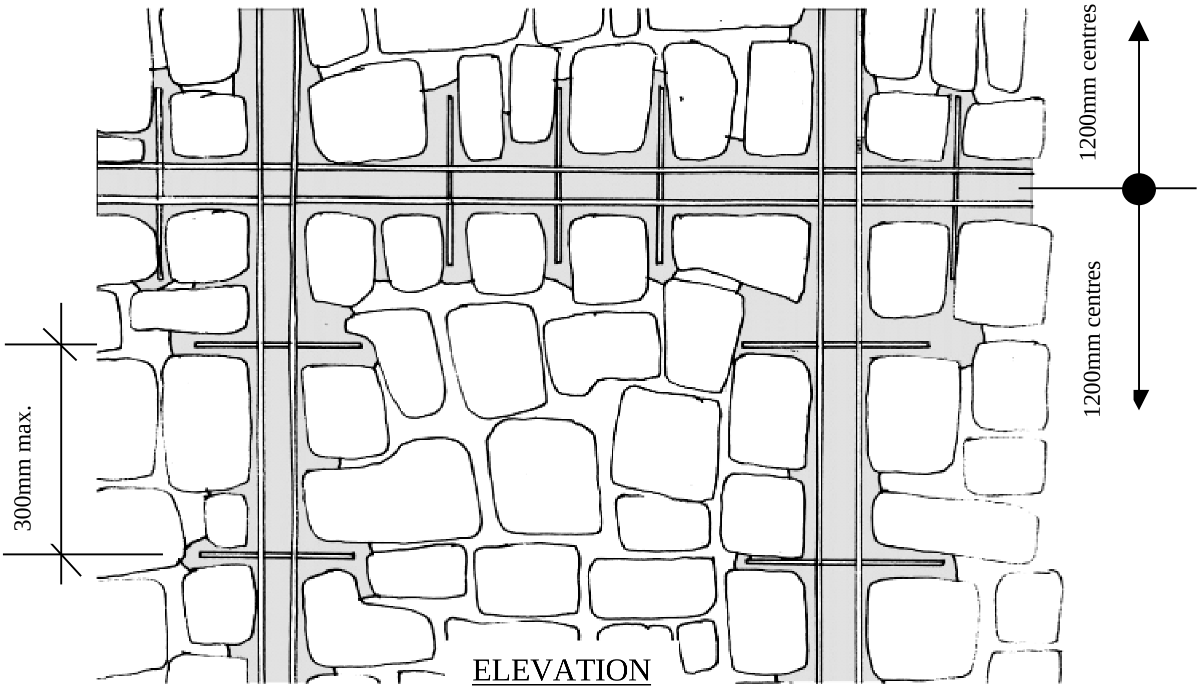
KEY POINTS;
A) Galvanized steel wire mesh (minimum 2mm diameter). Minimum laps to be 300mm
B) Tied together with steel through rods through the wall, at 300 – 400mm centres
C) Two coat cement/sand render 25mm to 50mm thick
D) Cut away loose material to sound wall

REASONS FOR USE AND COMMENTS

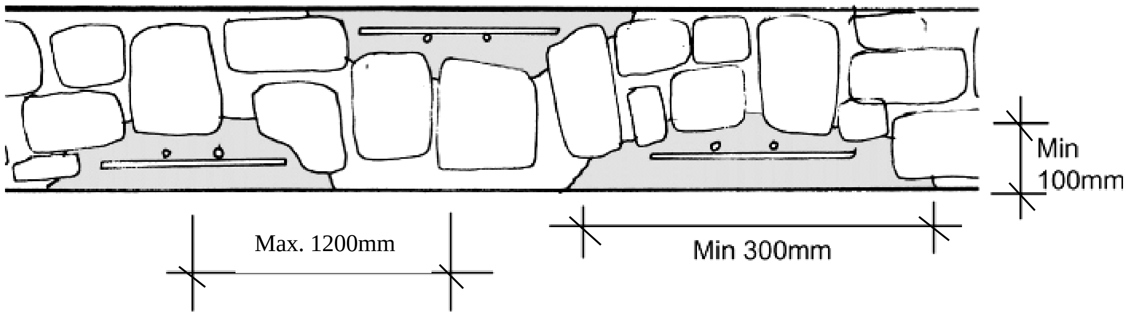
- Simplest form of repair to improve shear response and vertical load capacity.
- Improves binding of stones.

This detail is also applicable to masonry cut – stone or blockwork walls

B – Reinforced Concrete Stitching belts



ELEVATION



PLAN

CAUTION
A) Not to be used in weakly bonded walls.
B) Suitable for walls, where sand/cement mortar bedding has been used.
C) **This method may not be applicable for all types of types of rubble wall construction.**

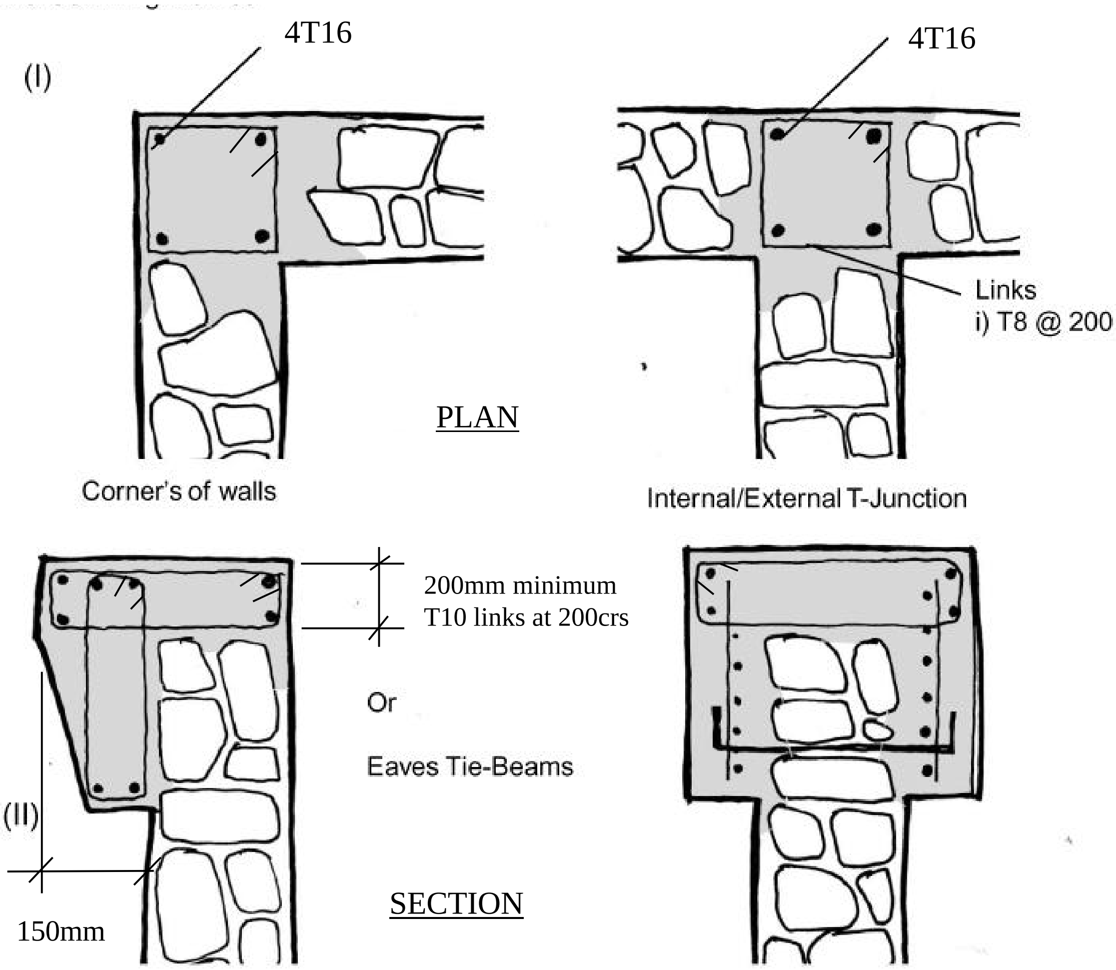
REASONS FOR USE AND COMMENTS

- Improve shear response and binding
- Limited use, depending on wall thickness (ideally for wall thickness greater than 450mm).
- Care required to avoid wall being weakened by over-cutting.
- For walls less than 450mm, carry out work on one face at a time.
- Avoid lapping bars in column bands.

Minimum bar diameter 8mm, all bars to be adequately tied.

C – Reinforced concrete confining bands

For 500mm typical wall thickness.

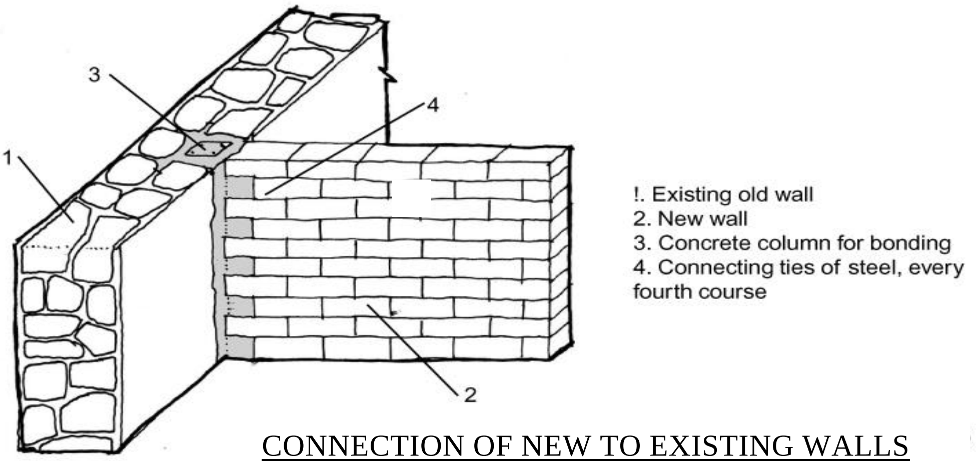


USE THE ABOVE DETAILS WHERE WALLS AND/OR ROOFS HAVE PARTIALLY COLLAPSED.

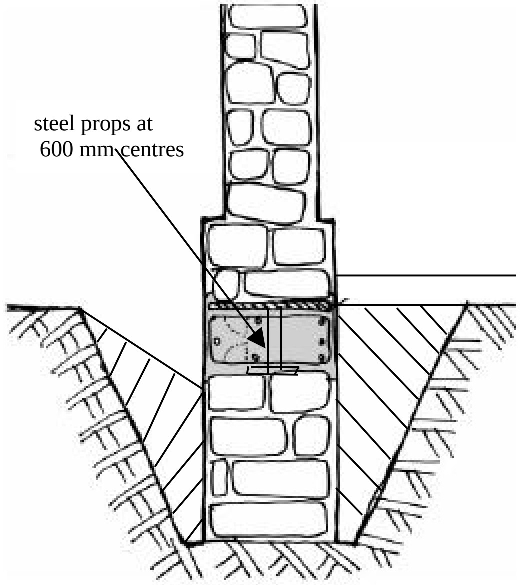
REBUILD WALLS WITH STRONG POINTS AND EAVES BEAMS.

REASONS FOR USE AND COMMENTS	
• Improved peripheral ties. • Improved stability. • Improved load transfer.	• Check condition of wall. • Rebuild all loose walls • Avoid overhang greater than 150mm
Caution : This method may not be applicable for all types of rubble wall construction. However, this detail is also applicable to masonry cut – stone or blockwork walls.	

C – Reinforced concrete confining bands



CONNECTION OF NEW TO EXISTING WALLS
OR EXISTING TO EXISTING WALLS



REINFORCED CONCRETE PLINTH AT GROUND LEVEL

1. Provide adequate temporary supports
2. Excavation on both sides may unavoidably disrupt services and finished floor details.
3. Wall cut-outs not to exceed 1200mm length at any point.
4. Total cut length per wall should not exceed 15% of the wall length.

Dry pack to fill voids or overfill concrete beam to avoid any air voids occurring.

REASONS FOR USE AND COMMENTS

- Improved peripheral ties.
- Improved stability.
- Improved load transfer.
- Beam acts as spreader and will bridge any localised weak spots in wall.
- Possibility of increasing foundation widths, if necessary.
- Make use of steel props for temporary supports, placed at 600mm centres.

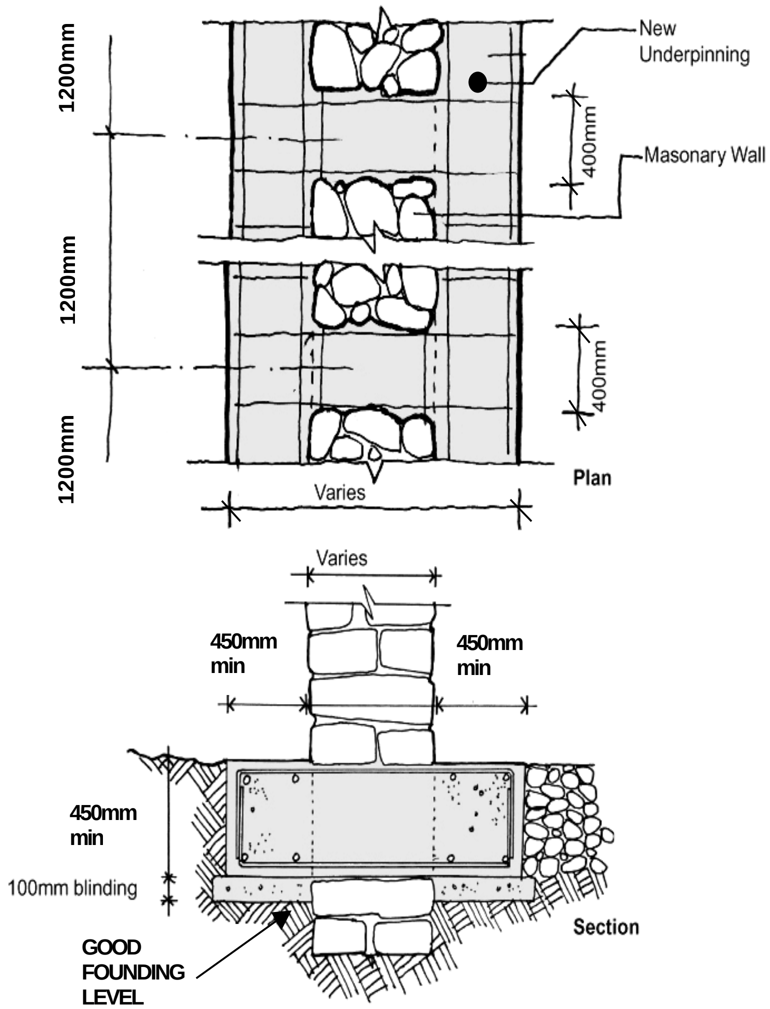
Caution: This method may not be applicable for all types of rubble wall construction.
However, this detail is also applicable to masonry cut – stone or blockwork walls.

REPAIRS AND STRENGTHENING:	RUBBLE MASONRY WALLS **Figure A5**

Foundations

Following options shown to suit boundaries / ownership

Option F1



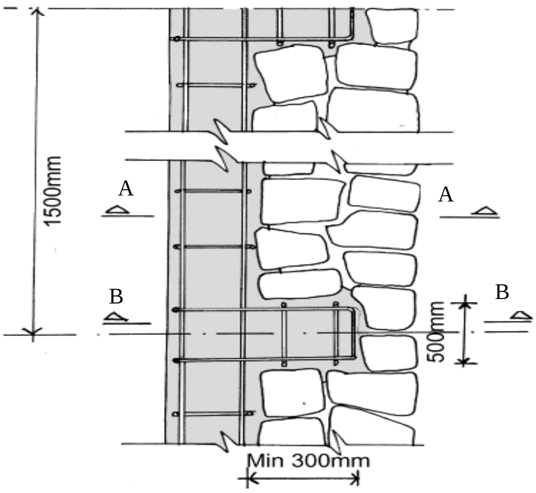
1. Sizes are indicative
2. New foundations should be on suitable bearing stratum
3. Minimum reinforcement is to be: main bars – 16mm dia., links to be 12mm at 200mm centres
4. Cover to all reinforcement bars to be 50mm

REASONS FOR USE AND COMMENTS

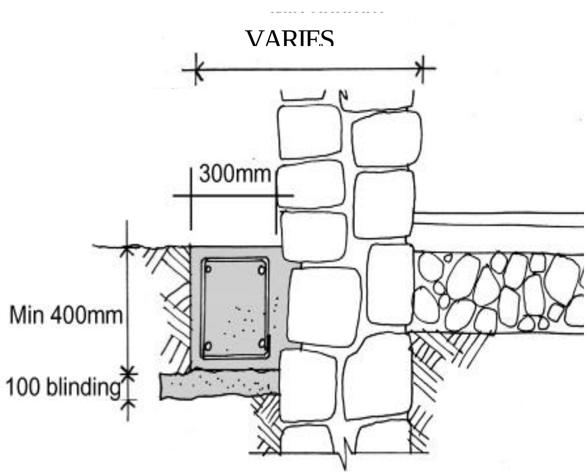
- Improved base shear.
- Reduces ground bearing pressure.
- Increased tying action
- Uniform load spread.

Caution: This method may not be applicable for all types of rubble wall construction.
This detail is also applicable to masonry cut – stone or blockwork walls.

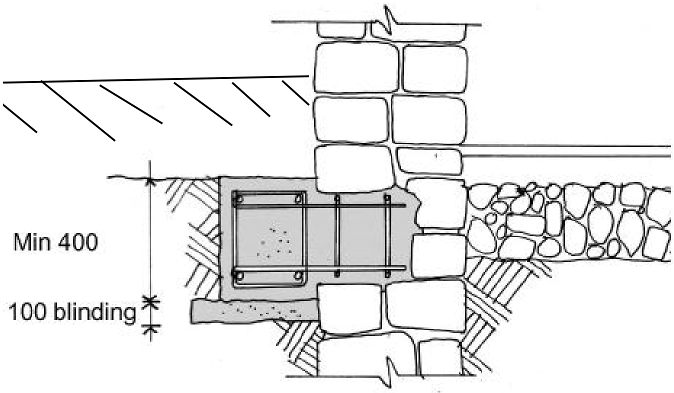
Foundations - Option F2 : Following option may be required to suit ownership boundaries.



PLAN



SECTION A – A



SECTION B - B

1 Sizes are indicative
2 New foundations should be on suitable bearing stratum and sized for building and seismic loading
3 Minimum reinforcements are to be: main bars – T16mm dia., links to be T10mm at 200mm centres

REASONS FOR USE AND COMMENTS

- Improved base shear.
- Reduces ground bearing pressure.
- Increased in tying action
- Uniform load spread.
- Minimum disruption to internal floor finishes

Caution: This method may not be applicable for all types of rubble wall construction.
This detail is also applicable to masonry cut – stone or blockwork walls.

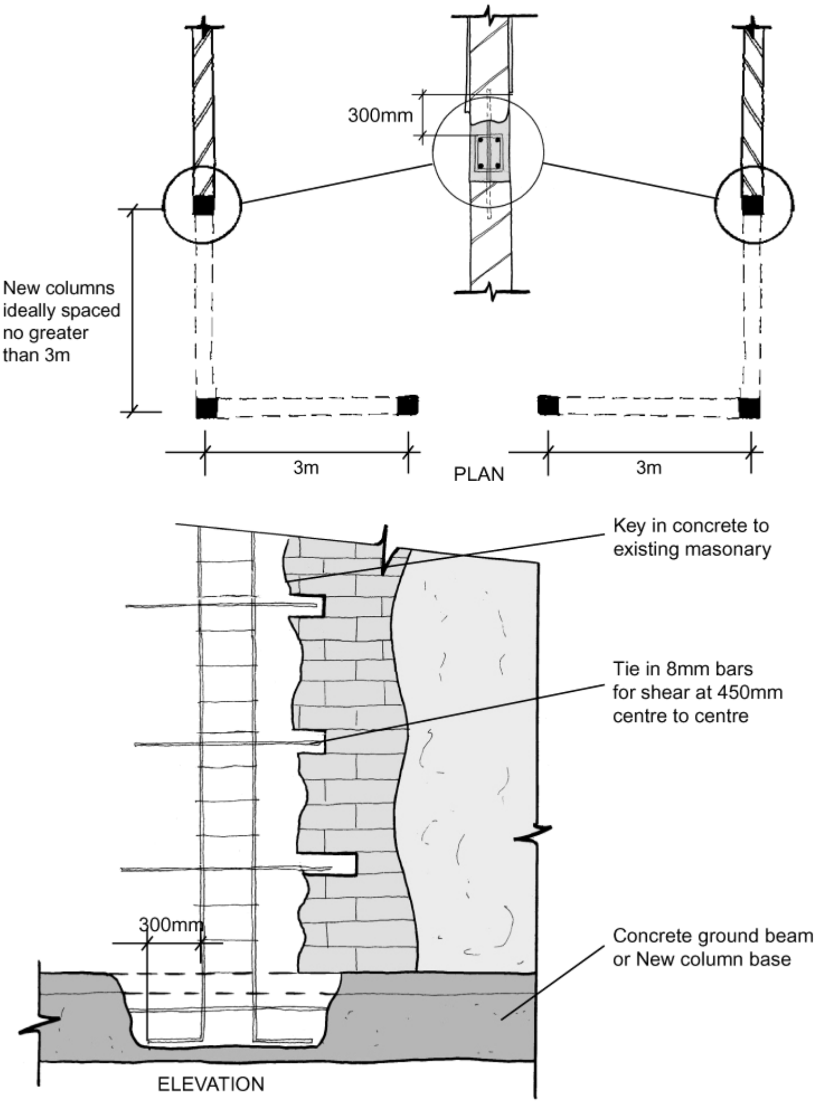
REPAIRS AND STRENGTHENING:	RUBBLE MASONRY WALLS **Figure A7**

APPENDIX B:
Repairs and Strengthening of Cut-Stone Masonry and Block Work Wall Buildings with Concrete Floors and Concrete orTimber Roof

Note:

Some of the Illustrations presented in Appendix B have been obtained from References 2,3,7 and 9

Introducing strong points to damaged buildings



MESH REINFORCEMENT IS ALSO APPROPRIATE, REFER TO FIGURES A1 AND A2.

B) Cut out damaged part of wall for new strong points
C) Minimum reinforcement: Main bars T12mm, Links T8mm at 200 centres (all high yield)
D) Refer to Figure B2 for tie detail at top.
E) Ensure concrete is adequately compacted and fill all voids to form good bonding to wall

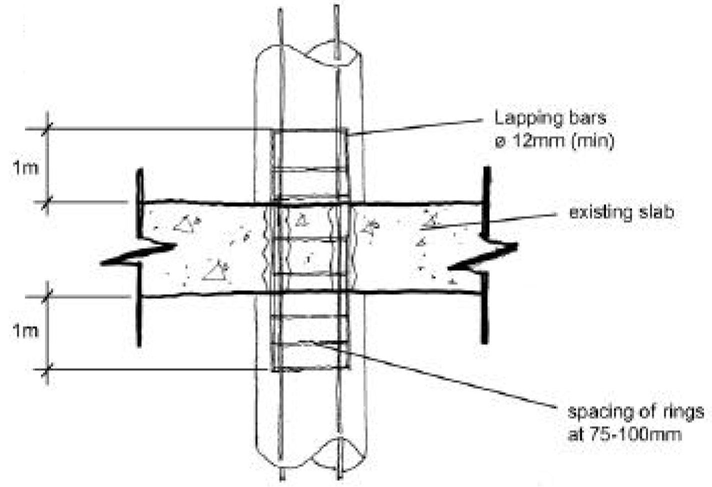
REASONS FOR USE AND COMMENTS

- Improves wall stability.
- Enhances load transfer to shear walls and foundations.

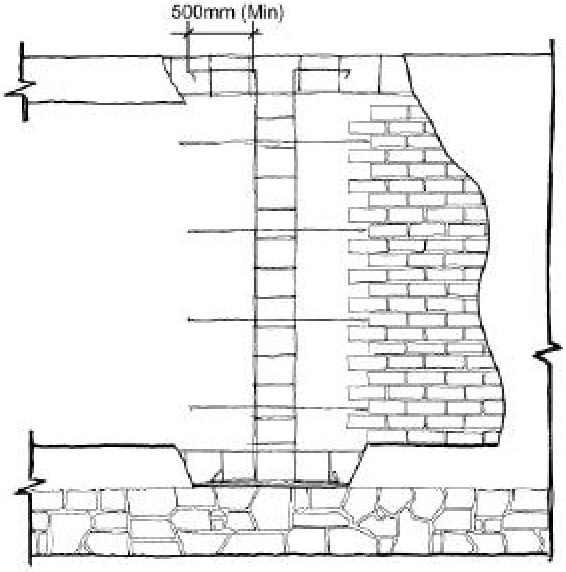
REPAIRS AND STRENGTHENING:	MASONRY CUT STONE OR BLOCKWORK WALLS **Figure B1**

Introducing strong points to damaged buildings - continued

a) Tie detail at floor/column junction (2 storey)



b) Detail showing ties at top and bottom (single storey)



1. Provide adequate support to wall
2. Cut out damaged part of wall for new strong points
3. Minimum reinforcement: Main bars T12mm, Links T8mm at 200 centres (all high yield)
4. Ensure concrete is adequately compacted and fill all voids to form good bonding to wall/floors

REASONS FOR USE AND COMMENTS

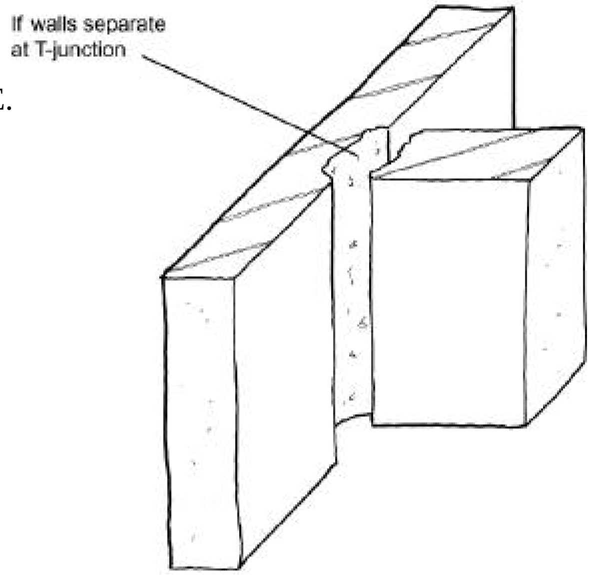
- Improves wall stability.
- Enhances load transfer to shear walls and foundations.

Provides continuity ties to floor and enhances diaphragm action.

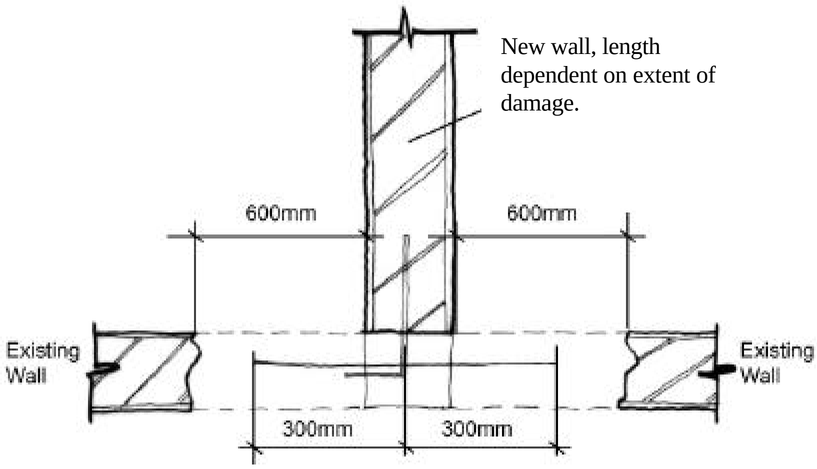
REPAIRS AND STRENGTHENING:	MASONRY CUT STONE OR BLOCKWORK WALLS **Figure B2**

T – junction wall ties

EXISTING DAMAGE.



REPAIR METHOD.



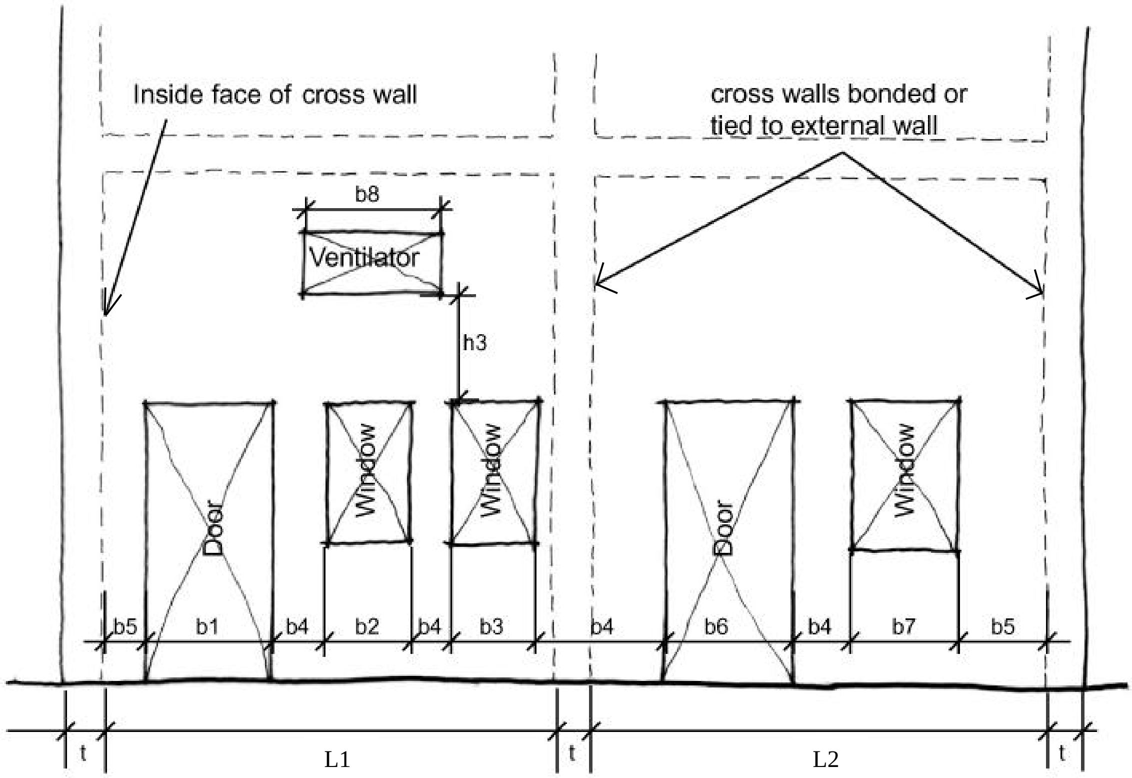
1) Mesh could be used, laid within mortar bed as an alternative.
2) All bars to be T10mm diameter and placed at 450mm centres
3) Rebuild with similar wall units

REASONS FOR USE AND COMMENTS

- Repairs and improves ties at junction.

REPAIRS AND STRENGTHENING:	MASONRY CUT STONE OR BLOCKWORK WALLS **Figure B3**

Guideline for openings in external walls (Ref: Indian Standards 4326)



b4 = at least 560mm (use larger dimensions if possible)
b5 = at least 450mm (use larger dimensions if possible)
h3 = at least 600mm (use larger dimensions if possible)

$\frac{b1 + b2 + b3}{L1}$ shall not exceed 0.42

$\frac{b6 + b7}{L2}$ shall not exceed 0.42

b8 = maximum 900mm use smaller dimensions if possible

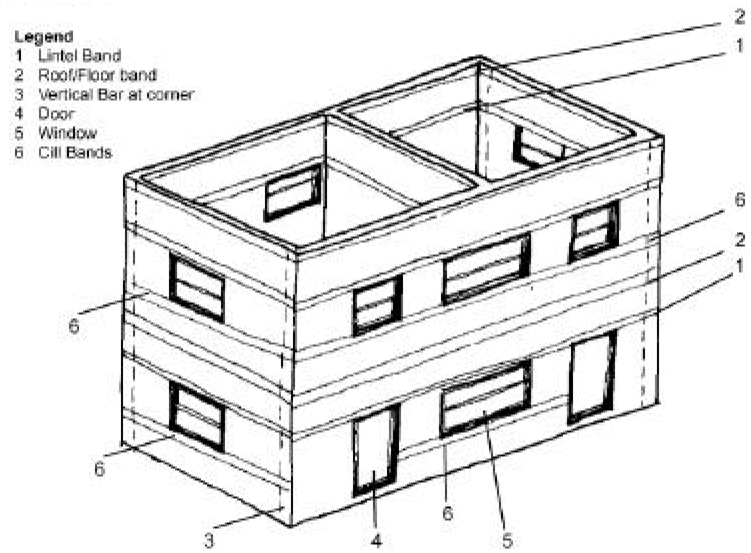
NOTE
1 Lintel bands and cill bands not shown. These are to be incorporated, see subsequent Figures B5 and B6.
2 Above openings and ratios are specific to 2 Storey structures. For other types refer to Indian Standards.

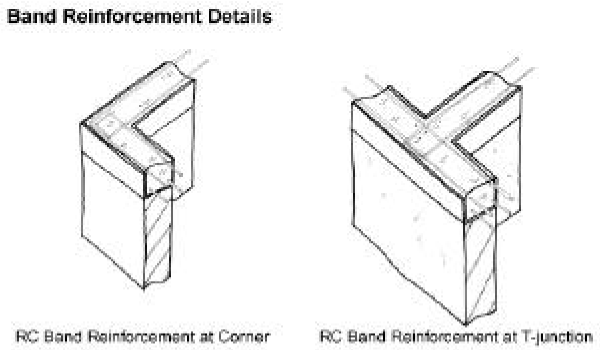
REASONS FOR USE AND COMMENTS

- Limitation of openings in walls
- TOO MANY DOORS AND WINDOW OPENINGS WILL REDUCE STRENGTH OF WALL

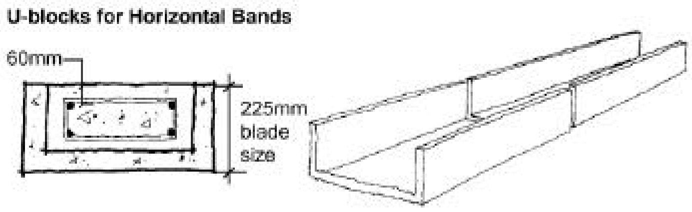
REPAIRS AND STRENGTHENING:	MASONRY CUT STONE OR BLOCKWORK WALLS **Figure B4**

Confining seismic bands   A) Flat roof case





Provide 4T16 diameter vertical bars to form strong points at corners and at tee junctions

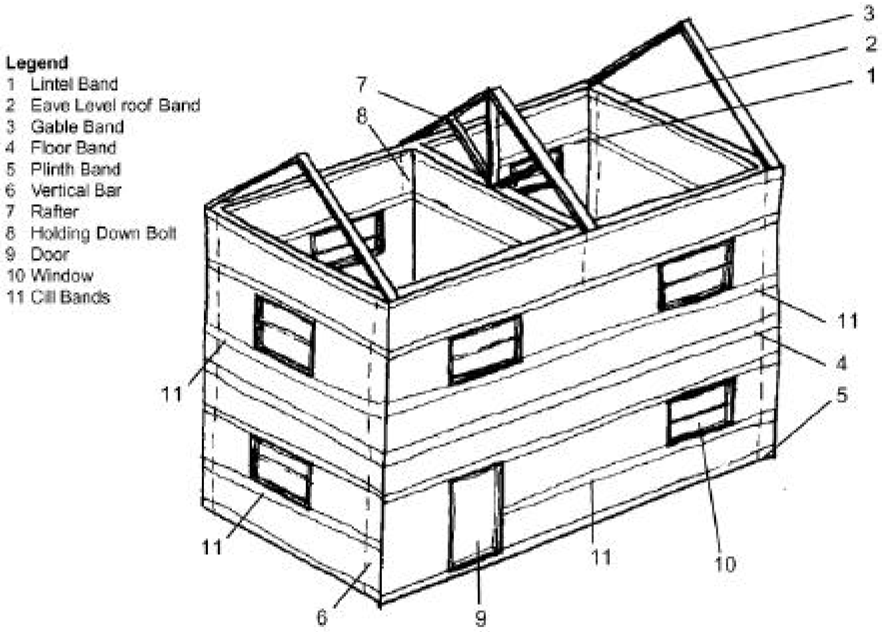


REASONS FOR USE AND COMMENTS

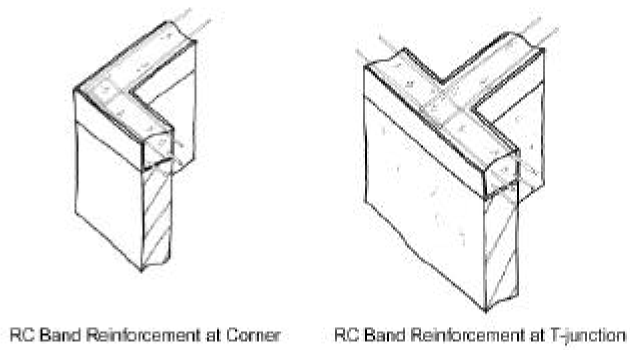
- Provides peripheral ties
- Improves wall confinement
- Better vertical and horizontal shear transfer
- Important to sequence construction work properly.
- In existing buildings concrete bands may be installed in short lengths (say 2.5m). Must not cut out full depth of wall at any one stage. Cast half from inside and remaining half from outside. Allow concrete to cure between stages. Fully dry pack all voids
- Concrete grade to be 20N/mm^2. Minimum concrete mix to be 1:2:4 (cement/sand/aggregate)

REPAIRS AND STRENGTHENING:	MASONRY CUT STONE OR BLOCKWORK WALLS **Figure B5**

Confining seismic bands B) Pitched roof case

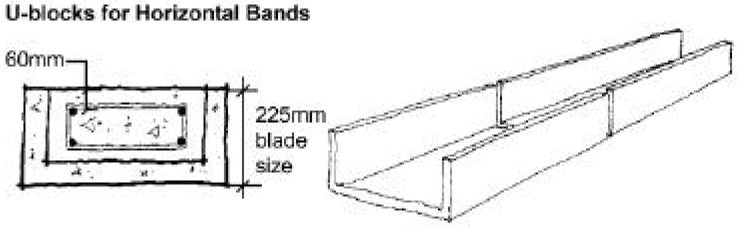


Band Reinforcement Details



Provide 4T16 diameter vertical bars to form strong points at corners and at tee junctions

U-blocks for Horizontal Bands



REASONS FOR USE AND COMMENTS

- Provides peripheral ties
- Improves wall confinement
- Better vertical and horizontal shear transfer
- Important to sequence construction work properly.
- In existing buildings concrete bands may be installed in short lengths (say 2.5m). Must not cut out full depth of wall at any stage. Cast half from inside and remaining half from outside. Allow concrete to cure between stages. Fully dry pack all voids.
  Concrete grade to be $20N/mm^2$. Minimum concrete mix to be 1:2:4 (cement/sand/aggregate).

REPAIRS AND STRENGTHENING:	MASONRY CUT STONE OR BLOCKWORK WALLS **Figure B6**

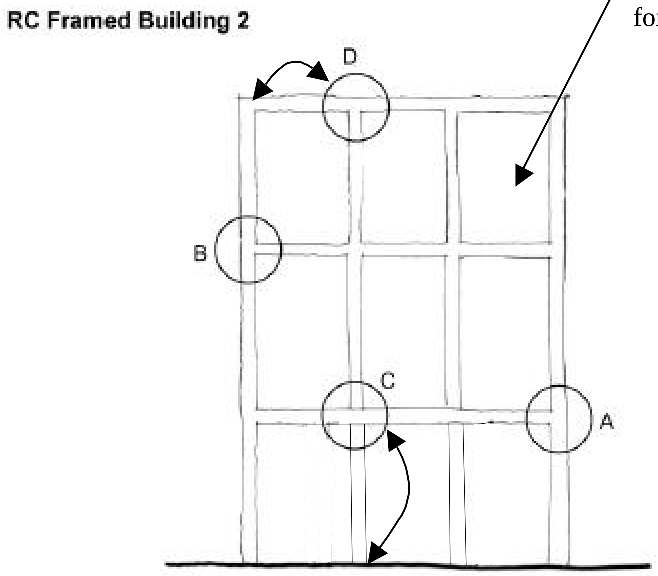
APPENDIX C:
Repairs and Strengthening of Reinforced Concrete Frame Buildings with Masonry or Blockwork Infill Wall Panels

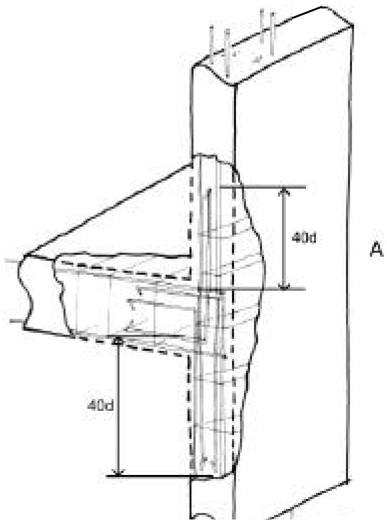
Note:

Some of the Illustrations presented in Appendix C have been obtained from References 2,3,7 and 9

Repairs to main structural elements

Infill walls between
columns not shown
for clarity





<u>Detail A: REPAIRS TO COLUMN BEAM JUNCTIONS</u>

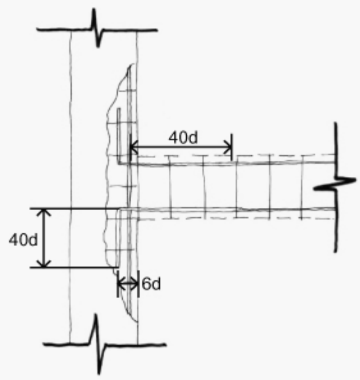
1) Provide adequate temporary supports to beam and column
2) Cut out damaged concrete to a square edge
3) Cut out damaged bars and provide new bars with adequate laps and anchorage
4) For spacing of links refer to Figure C3

REASONS FOR USE AND COMMENTS

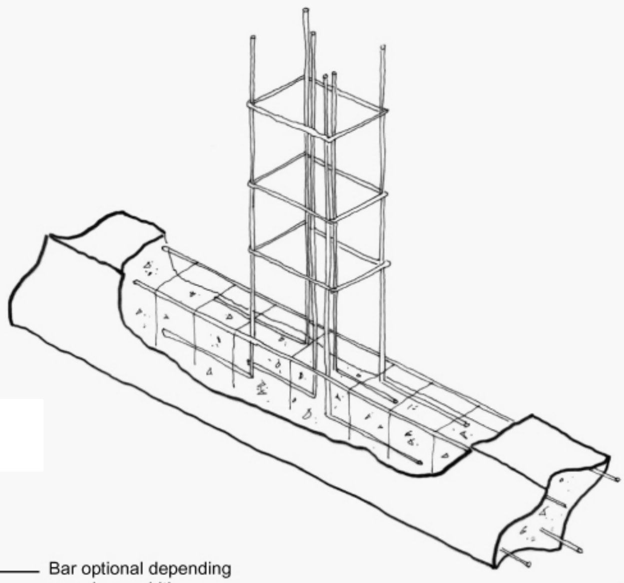
- Increases strength of column / beam junction
- Restores and improves ties
- Improves bending and shear resistance at junctions, particularly for reversal of loads.
- It is important that columns and beams are continuous through the connection and are not at an offset.

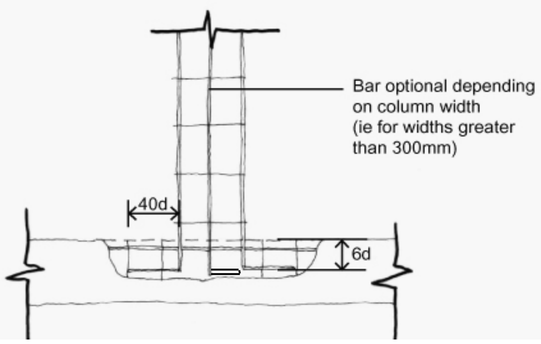
Repairs to main structural elements

Detail B: REPAIRS TO FLOOR BEAM/COLUMN ENDS



Detail C: REPAIRS TO COLUMN BASE





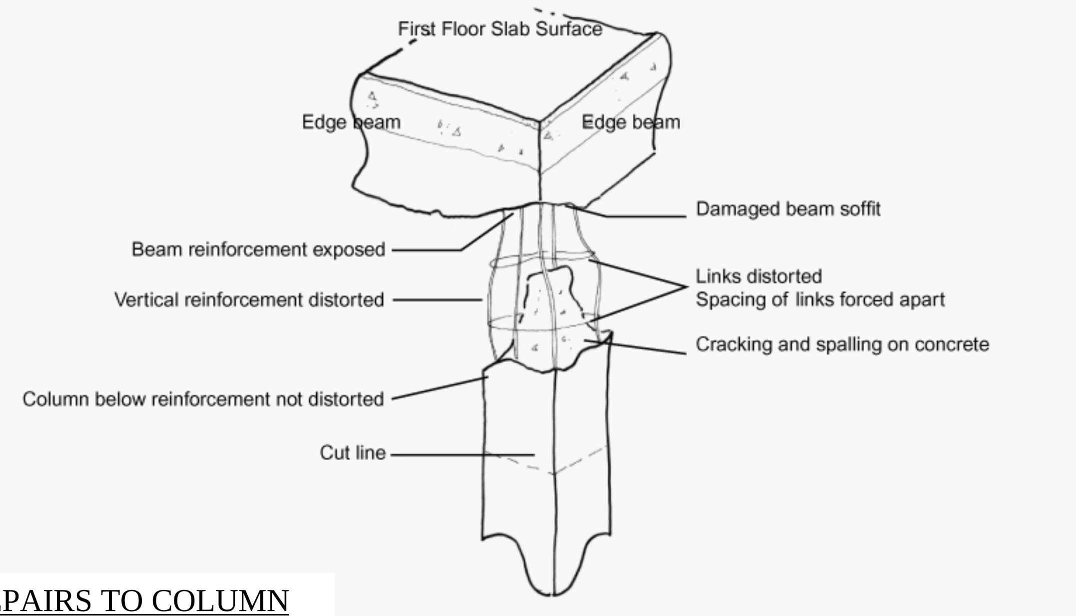
Restore infill panels between columns during repairs. For example rebuild walls first, use side as shutter, then cast concrete.

REASONS FOR USE AND COMMENTS

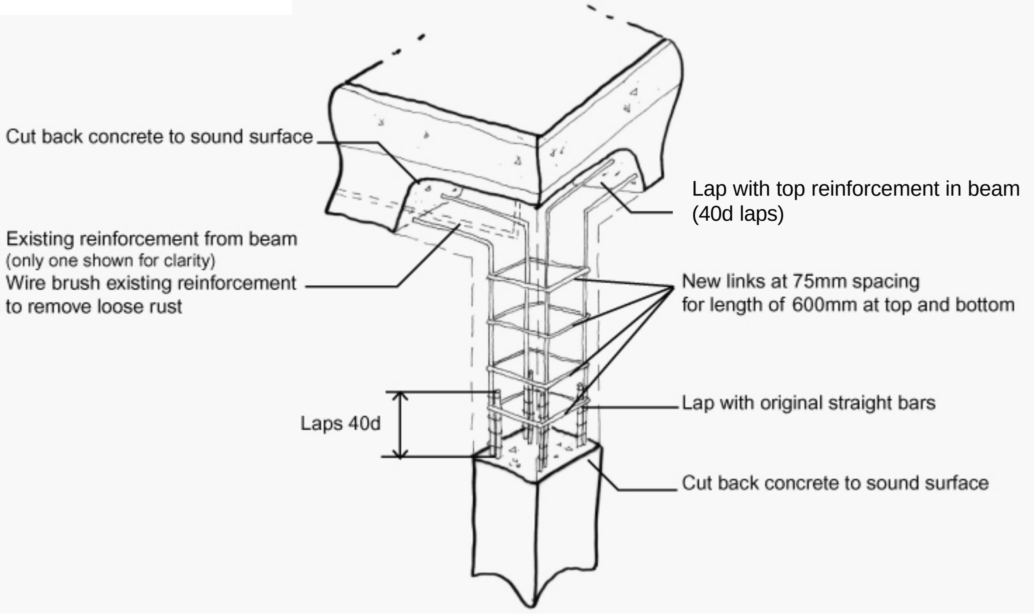
- Increases strength of column / beam junction
- Restores and improve ties
- Improves bending and shear resistance at junctions, particularly for reversal of loads.

REPAIRS AND STRENGTHENING:	CONCRETE FRAMED BUILDINGS **Figure C2**

Repairs to main structural elements



Detail D: REPAIRS TO COLUMN HEADS



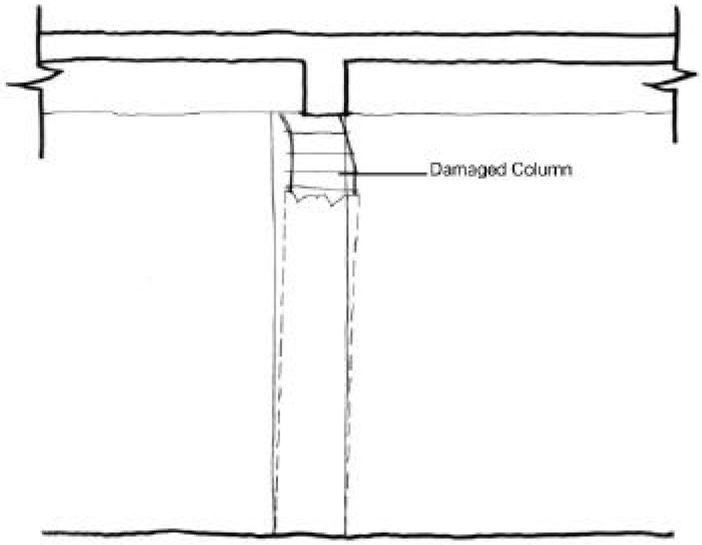
Notes:

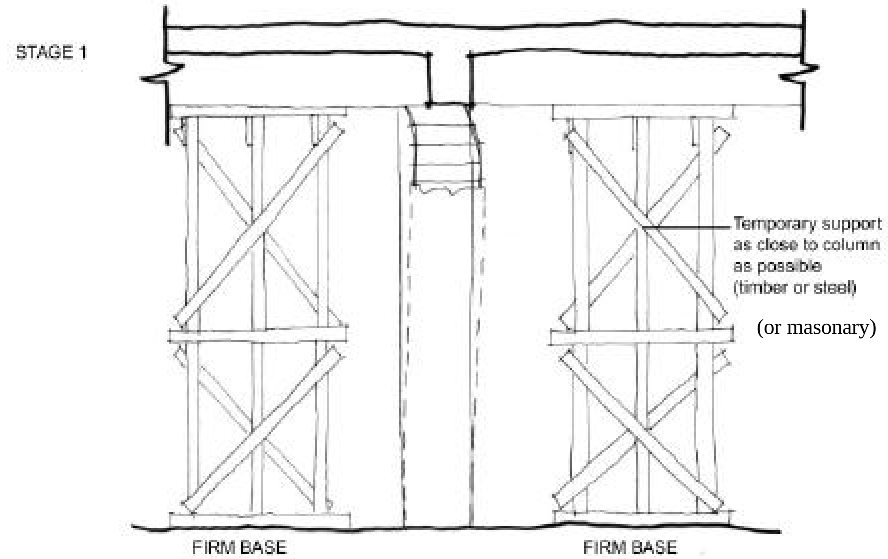
1 Provide adequate temporary supports
2 Restore infill panels between columns during repairs. For example, rebuild walls first, use side as shutter, and then cast concrete.

REASONS FOR USE AND COMMENTS

- Increases strength of column / beam junction
- Restores and improves ties
- Improves bending and shear resistance at junctions
- See Figures C4 to C6 for repair sequences

EXAMPLE OF SAFE SEQUENCE OF REPAIRS FOR AN INTERNAL COLUMN





Notes:

1) Provide adequate temporary supports
2) Restore infill panels between columns during repairs. For example rebuild walls first, use side as shutter, and then cast concrete.

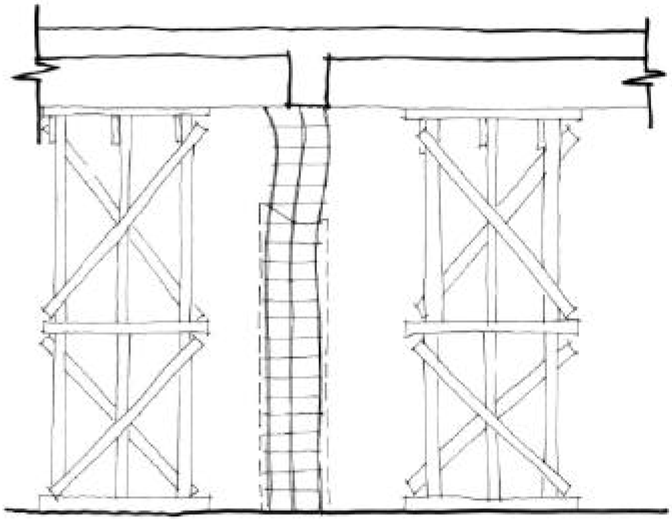
REASONS FOR USE AND COMMENTS

- Stage 1 - prop to support existing loads
- Make use of jacks where appropriate.

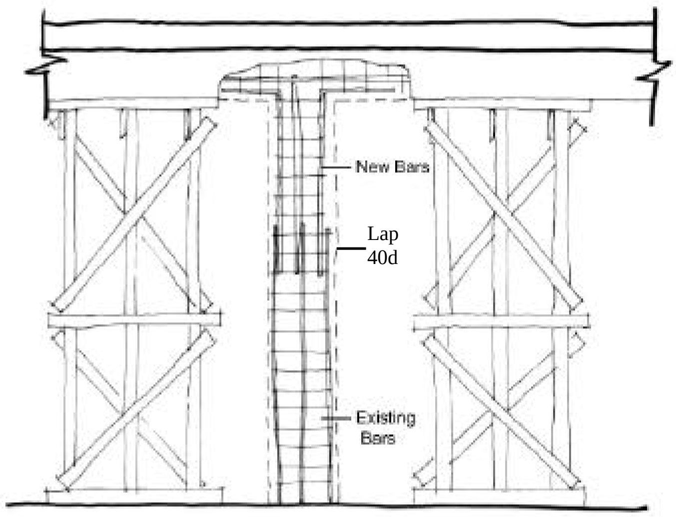
REPAIRS AND STRENGTHENING: Example	CONCRETE FRAMED BUILDINGS **Figure C4**

EXAMPLE OF SAFE SEQUENCE OF REPAIRS FOR AN INTERNAL COLUMN - CONTINUED

STAGE 2



STAGE 3



Notes:

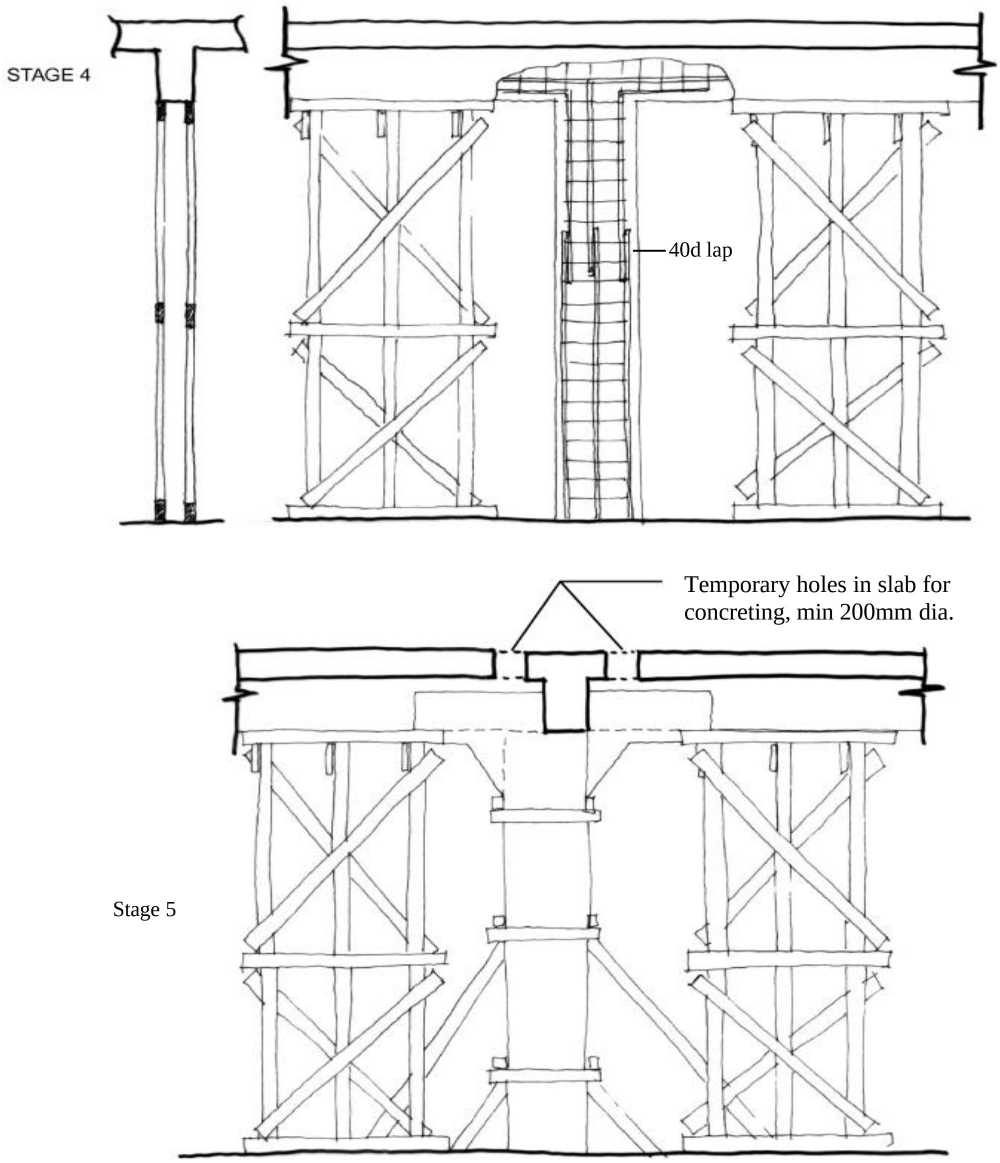
1) Provide adequate temporary supports
2) Restore infill panels between columns during repairs. For example rebuild walls first, use side as shutter, and then cast concrete.

REASONS FOR USE AND COMMENTS

Stages 2 & 3

- Expose damaged column reinforcement
- Add new bars, lapped onto existing undamaged bars
- Tie bars to beam above
- For link spacing refer to Figures C9 and C10.
- Ideally column bars should be lapped with beam bars above

EXAMPLE OF SAFE SEQUENCE OF REPAIRS FOR AN INTERNAL COLUMN - CONTINUED



REASONS FOR USE AND COMMENTS

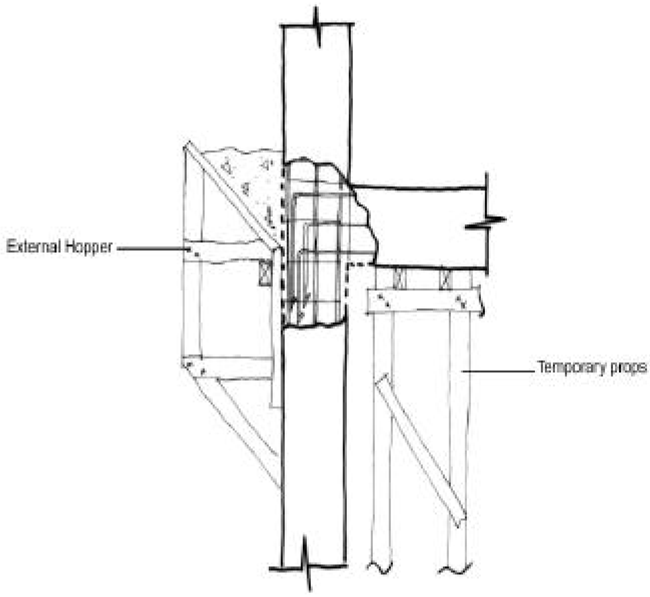
STAGES 4 & 5

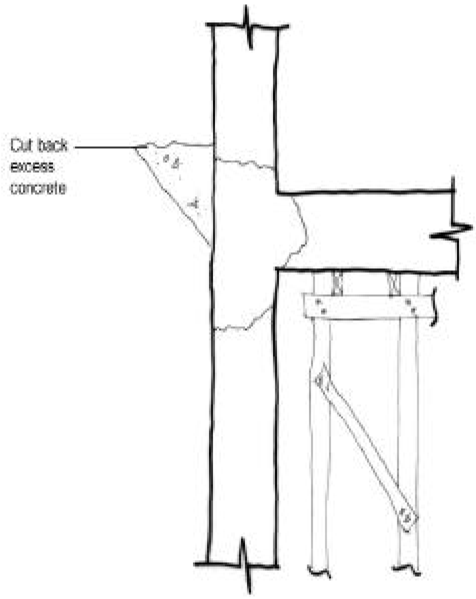
- Cut temporary holes in floor slab for concreting
- Form shutter box with hoppers
- Place concrete and vibrate to achieve adequate compaction. Avoid loss of grout through shuttering.
- Remove shutters on the following day
- Props to remain in place whilst curing for at least 14 days
- Restore infill panels between columns during repairs. For example rebuild walls first, use side as shutter, and then cast concrete.

REPAIRS AND STRENGTHENING: Example	CONCRETE FRAMED BUILDINGS **Figure C6**

EXAMPLE OF SAFE SEQUENCE OF REPAIRS:

TO EDGE COLUMN AND BEAM





REASONS FOR USE AND COMMENTS

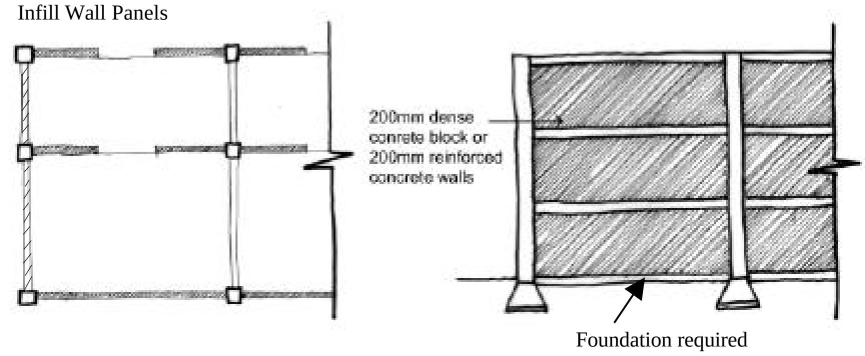
- Follow Stages 1 to 4 as illustrated in Figures C4 to C6
- Concrete final stage as above.

REPAIRS AND STRENGTHENING: Example	CONCRETE FRAMED BUILDINGS **Figure C7**

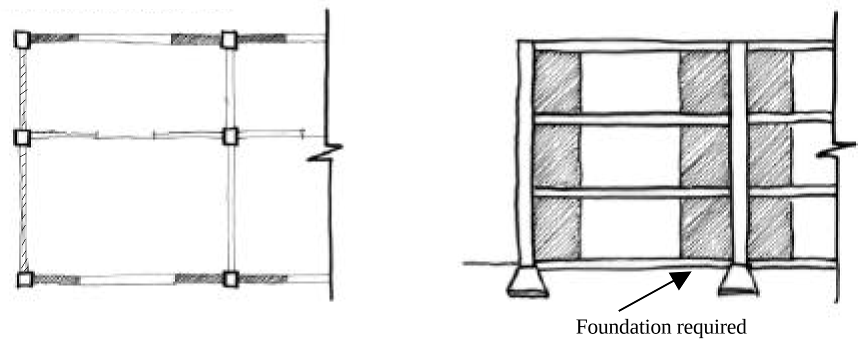
Infill walls using Blockwork or Cut Stone or Shear Walls in Reinforced Concrete

Note:
Shear walls must be in two directions

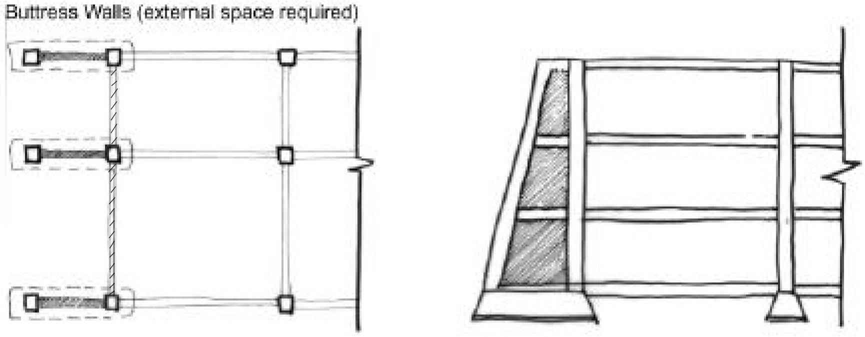
Infill Wall Panels



Partial infill wall panels



Buttress Walls (external space required)



Notes: 1) Ensure adequate ties between walls and columns

REASONS FOR USE AND COMMENTS

- Increases lateral resistance
- Avoids soft storey problems
- Increases overall stability
- Provides additional restraint to columns
- Provide shear walls in both directions (sketches shows shear walls in one direction only for clarity)
- For guidance on allowable number of openings in walls, see Fig. B4

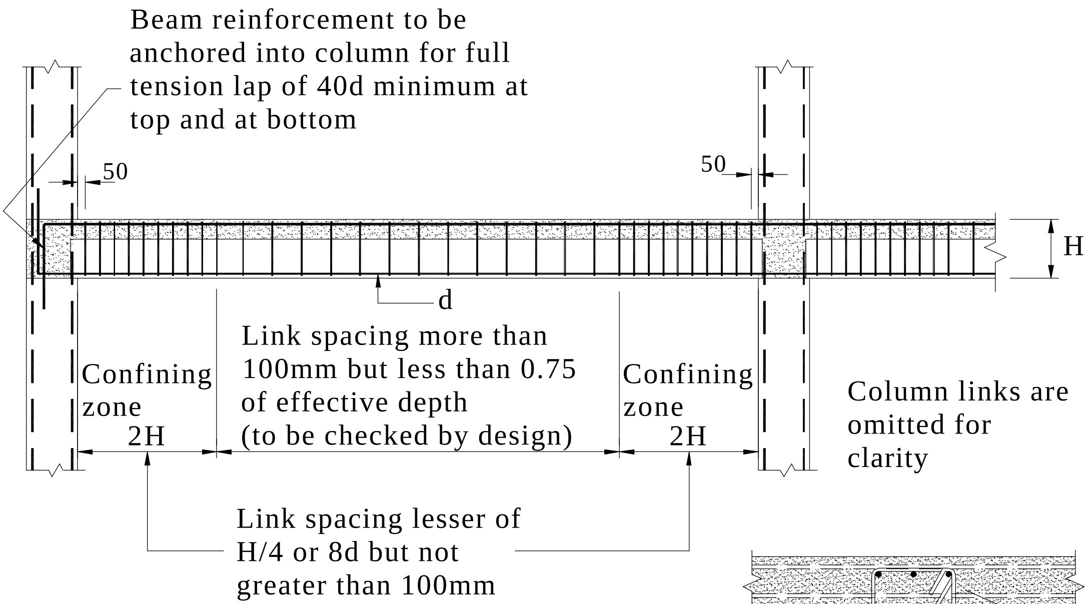
REPAIRS AND STRENGTHENING:	CONCRETE FRAMED BUILDINGS
	Figure C8

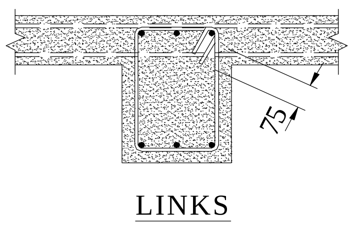
Detailing guide (beam)

Minimum of 3 bars for full length along top and bottom face should be used.

As (minimum) = 0.005 BH on any face
As (maximum) = 0.025 BH on any face

As = Total cross section of steel bars to be used
B = breadth of beam
H = depth of beam
d = diameter of longidudinal bars





Effective depth = H - cover - link - d/2

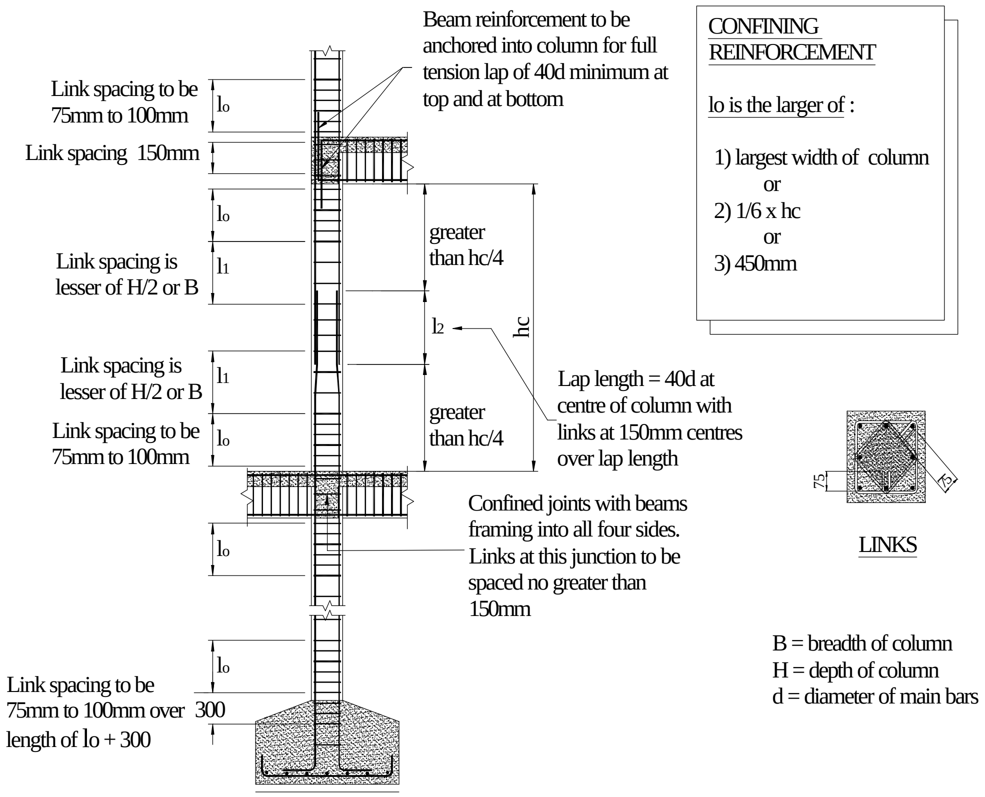
Notes:
Concrete strength to be 20 N/mm^2 (minimum)
Cover to bars to all sides: Beams – 35mm
Slabs – 25mm
Columns – 40mm
Ground beams – 50mm
Foundations – 75mm
All reinforcement to be high yield (ribbed bars)

REASONS FOR USE AND COMMENTS

- Beams should be reinforced top and bottom and anchored at ends with full tension laps.
- Reinforcement sized to allow for ductile behaviour (sized after calculations). Minimum steel should be 3No. 16mm diameter bars at top and bottom.
- Link spacing to be as shown (note close spacing at ends). Minimum size of links in confining zones should be 10mm diameter based on 75mm centres.
- Provide full continuity at column supports for reversal of forces.
- Ends of links should be turned into the body of beam or column by at least 75mm

REPAIRS AND STRENGTHENING:	CONCRETE FRAMED BUILDINGS **Figure C9**

Detailing guide (column)



Notes:
Concrete strength to be 20 N/mm^2 (minimum)
Cover to bars to all sides: Beams – 35mm
Slabs – 25mm
Columns – 40mm
Ground beams – 50mm
Foundations – 75mm
All reinforcement to be high yield (ribbed bars)

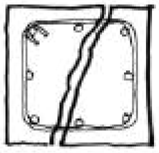
REASONS FOR USE AND COMMENTS

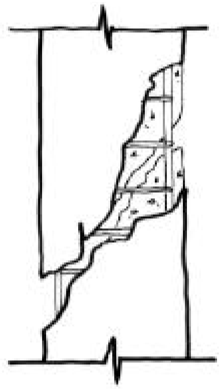
- Columns should be reinforced with minimum of 8 bars, with links as shown. Bars should be lapped at mid height of column with full tension laps.
- Reinforcement sized to allow for ductile behaviour (sized after calculations). Minimum vertical steel should be 8 No. 16mm diameter bars, with 10mm diameter links
- Link spacing to be as shown (note close spacing at ends and at lap positions). Minimum size of links in confining zones should be 10mm diameter based on 75mm centres.
- Provide full continuity at column/beam junctions for reversal of forces.
- Bar spacing to be restricted to 200mm maximum. All main bars to be tied with links.
- Ends of links should be turned into the body of beam or column by at least 75mm
- Provision of shear walls is necessary to resist seismic lateral loads.

Jacketing (Columns) – To increase structural capacity (seek structural engineers advice)

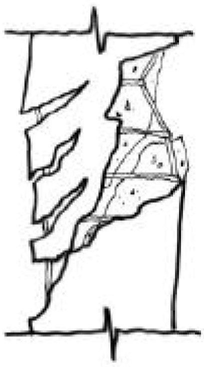
Damaged column should be repaired before Jacketing.

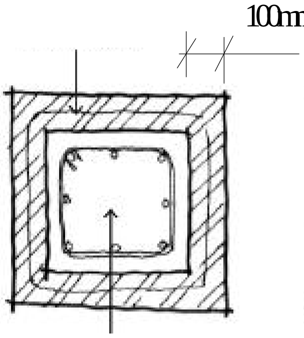
Where jacketing is used it should be done in the manner shown in Figure C10 and taken down to foundation and tied into surrounding structural elements for flexural strength



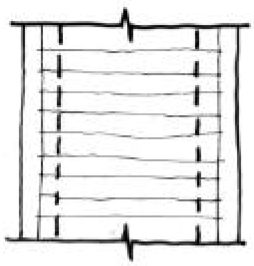


Jacketed column with 100mm added concrete section with new bars and links. Use 10mm aggregates





Existing damaged column strengthened after repair, by jacketing



Containment reinforcement as Figure C10

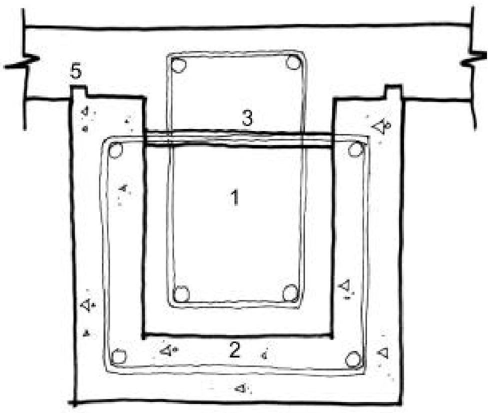
Concrete strength to be 20 N/mm^2 (minimum)
Cover to bars to all sides: Beams – 35mm
Slabs – 25mm
Columns – 40mm
Ground beams – 50mm
Foundations – 75mm
All reinforcement to be high yield (ribbed bars)

REASONS FOR USE AND COMMENTS

- Provide adequate temporary supports to all damaged columns and beams down to foundations.
- Cut out damaged concrete
- Columns should be reinforced with a minimum of 8 bars, with links as recommended. Bars should be lapped at mid height of column with full tension laps (40d min). **Bars must be continued and anchored into adjoining members**.
- Reinforcement sized to allow for ductile behaviour (sized after calculations). Minimum steel should be 8 No. 16mm diameter bars, links 10mm diameter bars
- Link spacing to be as specified by design (note, must be close spacing at ends and at lap positions).
- Full continuity should exist for reversal of forces.
- Bar spacing to be restricted to 200mm maximum. All bars to be tied with links
- Jacketing thickness should be 100mm minimum. Aggregate size should be restricted to 10mm.

REPAIRS AND STRENGTHENING: Jacketing Columns	CONCRETE FRAMED BUILDINGS **Figure C11**

Jacketing (Beams) – To increase structural capacity (seek structural engineers advice)



Beam width to suit structural design

1. Old concrete
2. New concrete 10mm aggregates
3. Holes for passing stirrups
4. Chip old surface
5. Groove in slab

Notes:

(a) Damaged beam must be adequately repaired before jacketing.
(b) New reinforcement must be tied into columns/walls for flexural strength and anchorage, see Fig C9
(c) Concrete strength to be 20 N/mm^2 (minimum)
(d) Cover to bars to all sides: Beams – 35mm
Slabs – 25mm
Columns – 40mm
Ground beams – 50mm
Foundations – 75mm
(e) All reinforcement to be high yield (ribbed bars)

REASONS FOR USE AND COMMENTS

- Beams should be reinforced with minimum of 4 bars, with links as recommended. **Bars must be continued and anchored into adjoining members**.
- Reinforcement sized to allow for ductile behaviour (sized after calculations). Minimum steel should be 4 No. 16mm diameter bars, links 10mm diameter bars
- Link spacing to be as recommended (note, close spacing at ends and at lap positions).
- Full continuity should exist for reversal of forces.
- All main bars to be tied with links.
- Jacketing thickness should be 100mm minimum. Aggregate size should be restricted to 10mm.

REPAIRS AND STRENGTHENING: Jacketing Beams	CONCRETE FRAMED BUILDINGS **Figure C12**

APPENDIX D:
Good Practice Notes for New Build

Table D1 : GOOD PRACTICE NOTES FOR NEW MASONRY BUILDINGS

(note brickwork walls not considered here as they are not widely used in Kutch)

Building location	• Check location of building • Is building on fill soil, near toe of hillside, on the sloping ground, on coastal area or on loose sand close to water ? • If yes, gain specialist Geotechnical advice as the area may be unstable or ground may liquefy. Specialised ground treatment works and/or foundation types are required.
Required Material types	• Concrete blockwork units • Cut-stone masonry units • Reinforced Concrete walls • Factory manufactured brick units • Avoid using random rubble masonry and adobe wall units unless you have specialist help.
Structural form and building configuration	• Avoid creating heavy concentrated masses, particularly at roof level (eg large water tanks) • Make sure no heavy masses are located above stairwells or lift shafts etc. • Avoid irregular floor plan shapes to avoid torsional effects in earthquakes • Make sure columns and walls are continuous between floors • Make sure buildings do not have large openings (eg for garages or shops) as these can weaken structure and cause torsional effects • Make sure that building's plan shape at any floor level, including ground floor, is symmetrical • If shear walls are concentrated inside a building make sure it will not be subject to torsional effects or design structure, to resist this. • If buildings must be asymmetrical, split parts of it into rectangles by creating movement gaps. Gaps to be minimum 30mm per floor to avoid adjacent buildings clashing during horizontal sway in an earthquake • Make sure structure is not long in relation to its width (W). Avoid long unsupported walls of longest length (L) does not exceed 3W.
Foundations	• Check soil type and water level • Guidance on assessment of soil strength from pits or boreholes is given in Annex 3 (no account taken of earthquakes; see Indian codes for guidance). • Reassess soil strength for seismic design of foundations using Indian codes. • Use reinforced concrete strip footings under main load bearing walls. • Soft clays and loose-medium dense sand, which is waterlogged, may liquefy during an earthquake. Avoid area or seek specialist advice on piled foundations and structural design.
Shear walls	***Masonry Walls acting as non- structural " shear" walls to resist lateral shaking:*** • Make sure wall units are made with good strength (minimum Grade 35N/mm^2) • Make sure all external and internal walls are continuous, and interlocked with toothed details at L and T corners of all wall connections • Use vertical steel bars (in a mortar bed) at all wall corners, continuously from plinth to roof level. **Alternatively, consider using galvanised wire mesh detail inside and outside to seismically strengthen corners.** • All masonry units to be bonded with mortar of 1 part cement to 3 parts sand ratio. • Make sure all walls are continuous from foundations to roof level • Make sure masonry buildings do not exceed 3-storey height plus roof. Also, ensure floor heights do not exceed 3.5m at any storey. ***Reinforced Concrete Walls*** • These can be designed including corners as L shaped reinforced walls to resist horizontal forces from ground to roof level. They have to be properly designed and may restrict openings to corners unless other measures are taken • This method is not normally used as it is expensive.
Window/Door Openings	• Restrict window/door openings to minimum so that walls can better resist seismic loads • Ensure window or door openings do not exceed dimensions in code. See Appendix B4 for details. • Make sure that the total length of openings does not exceed 40% of the length of wall between consecutive cross walls for 2-storey buildings, or 33% for 3-storey, and 50% for single storey buildings. • Make sure that top level of door and window openings is constant to enable lintel bands to be easily placed over total length of wall face.
Peripheral ties	• Make sure that ground beams are installed at below plinth level for untied footings

	• Make sure that lintel bands are used over door and window openings along the total length of the wall • It is also advisable to construct cill bands beneath window openings in same way • Alternatively, frame each door or window with a continuous reinforced concrete (RC) band (but this may be less seismically effective as it may be difficult to construct and bond to wall) • Construct a RC band at roof level above the wall. • Use RC gable bands to frame gable walls where these occur.
Slab and beams detail	• Ground floor slabs should not bear on loose sand or sand fill that is not properly compacted. (Uncompacted soils will settle creating voids under slab following an earthquake.) • Floor slabs should be continuous with walls • Modern Roof slabs in Kutch are generally concrete flat roofs and have performed reasonably well because of diaphragm action being achieved with cut stone or blockwork walls.
Roof Types and Detailing	• Avoid using gable walls to roofs. If unavoidable use RC gable bands as above • Use pitched or flat roofs • Pitched roofs need to be adequately braced to walls and roof bands. They also need adequate bracing of the roof frame. • Tiles should be nailed into batterns etc
Minimum beam, column and slab sizes	**FOR GUIDANCE ONLY** • Studies from this earthquake have shown that floor slabs and beams for domestic properties of following sizes have worked: - 3m span concrete floor slabs, minimum depth 150mm - 4.5m span beams, minimum 450mm deep by 300mm wide. - Concrete columns – average 350mm x 350mm (not normally seen with complete masonry building) • Make sure that all main reinforcing bars in concrete are high yield deformed bars , not plain bars. Links could be either. Make sure that all links have ends tucked back into the column.
Other Points	• Avoid having - Large water tanks on roof - cantilever balconies; - unreinforced parapets at roof level - architectural decorative motifs above 1.5m - free standing walls which fall over under lateral loading - roof tiles not fixed on to batterns • Do not place services through corners of buildings inside masonry units as these can weaken corners. Equally do not put rainwater pipes or any other pipes into corner walls • Make sure drainage and service pipes are not cast inside walls at plinth level.

Table D2 : GOOD PRACTICE NOTES FOR NEW REINFORCED CONCRETE BUILDINGS

(It is assumed that the reinforced concrete frame carries vertical load from the structure, with masonry walls taking minimum 75% horizontal earthquake loads).

Building location	• Check location of building • Is area to be built up in fill area, near toe of hillside, on sloping ground, on coastal area or on loose sand close to water ? • If yes, gain specialist Geotechnical advice as area may be unstable or ground may liquefy. Specialised ground treatment works and/or foundation types are required
Required material types for shear walls	• Concrete blockwork units • Cut-stone masonry units • Reinforced Concrete walls (expensive alternative) • Factory manufactured brick units • Avoid using random rubble masonry and adobe infill walls
Structural form and building configuration	• Avoid creating heavy concentrated masses, particularly at roof level (eg large water tanks) • Make sure no heavy masses are located above stairwells or lift shafts etc. • Avoid irregular floor plan shapes to avoid torsional effects in earthquakes • Make sure columns and walls are continuous between floors • Make sure buildings do not have large openings (eg for garages or shops) as these can weaken structure and cause torsional effects • Make sure that building's plan shape at any floor level, including ground floor, is symmetrical • If shear walls are concentrated inside a building make sure it will not be subject to torsional effects or design structure, to resist this. • If buildings must be asymmetrical, split parts of it into rectangles by creating movement gaps. Gaps to be minimum 30mm per floor to avoid adjacent buildings clashing during horizontal sway in an earthquake • Make sure structure is not long in relation to its width (W). Avoid long unsupported walls of longest length (L) does not exceed 3W.
Foundations	• Check soil type and water level • Guidance on assessment of soil strength from pits or boreholes is given in Table 3 (no account taken of earthquakes; see Indian codes for guidance). • Reassess soil strength for seismic design of foundations using Indian codes. • Use reinforced concrete strip footings under main load bearing walls. • Soft clays and loose-medium dense sand, which is waterlogged, may liquefy during an earthquake. Avoid area or seek specialist advice on piled foundations and structural design.
Masonry Shear walls	***Masonry Walls acting as non-structural walls to resist lateral shaking:*** • Make sure walls are made with good strength (minimum grade $35N/m^2$) • Make sure walls are built first and use walls as shutters for columns to give strong bonding between masonry wall and column. • All masonry units to be bonded with mortar, 1 part cement to 3 parts sand. • Make sure all walls are continuous from foundations to floor level. Cast beams and slab over walls *Reinforced concrete Walls* These can be combined with columns to provide additional shear resistance against earthquakes.
Window/Door Openings	• Restrict window/door openings to minimum so that walls can better resist seismic loads • Ensure window or door openings do not exceed dimensions in code. See Appendix B4 for details. • Make sure that the total length of openings does not exceed 40% of the length of wall between consecutive cross walls for 2-storey buildings, or 33% for 3-storey, and 50% for single storey buildings. • Make sure that top level of door and window openings is constant to enable lintel bands to be easily placed over total length of wall face.
Peripheral ties	• Make sure that ground beams are installed at below plinth level for untied footings • Make sure that lintel bands are used over door and window openings along the total length of the wall • It is also advisable to construct cill bands beneath window openings in same way • Alternatively, frame each door or window with a continuous reinforced concrete (RC) band (but this may be less seismically effective as it may be difficult to construct and bond to

	wall) • Construct a RC band at roof level above the wall. • Use RC gable bands to frame gable walls where these occur.
Slab and beams detail	• Ground floor slabs should not bear on loose sand or sand fill that is not properly compacted. • Ist and 2nd Floor slabs should continue **past** face of walls • Modern Roof slabs in Kutch are generally concrete flat roofs and have performed well because of diaphragm action being achieved with cut stone or blockwork walls.
Roof Types and Detailing	• Avoid using gable walls to roofs. If unavoidable use RC gable bands as above • Use pitched or flat roofs • Pitched roofs need to be adequately braced to walls and roof bands. They also need require adequate bracing. • Clay tiles should be nailed into batterns etc
Minimum beam, column and slab sizes	**FOR GUIDANCE ONLY** • Studies from this earthquake have shown that floor slabs and beams for domestic properties of following sizes have worked: - 3m span concrete floor slabs, minimum depth 150mm - 4.5m span beams, minimum 450mm deep by 300mm wide. - Concrete columns – average 350mm x 350mm • Make sure that all main reinforcing bars in concrete are high yield deformed bars, not plain bars. Links could be either. Make sure that all links have ends tucked back into the column • Make sure main column bars are properly lapped into beams for reversal of loads • Use minimum Grade M20 concrete. • Vibrate all concrete without causing excessive bleeding or grout loss
Other Points	• Avoid having - Large water tanks on roof - Long cantilever balconies; - unreinforced parapets at roof level - architectural decorative motifs above 1.5m - free standing walls which fall over under lateral loading - roof tiles not fixed to batterns • Do not place services through corners of buildings inside masonry units as these can weaken corners. Equally do not put rainwater pipes into corner walls • Make sure drainage services are not cast inside walls at plinth level. • Avoid having canopy structures with slender columns, as they are weak in resisting shear, and soft storey type collapse can occur.

APPENDIX E:
Building Damage Assessment Forms and Damage Classification of Buildings after an Earthquake

TABLE E1 - BUILDING DAMAGE ASSESSMENT FORM 1 OF 2

GREAT – Gujarat Relief Engineering Advice Team

PLEASE FILL IN Pre-Questionnaire below :

Name of Person:	**Town/Village in Kutch**	**Town/Village if outside Kutch**
Contact Details	**Telephone Nos:** **Business**: **Home:**	**Fax address:** **Email address:**

What is your BUILDING TYPE?	No/ Yes	Are your walls made of Masonry Stone (M)?	Are your walls made of concrete blockwall (CB)?	Are your walls made of rubble stone or uneven blockwork(RS)?
A. Reinforced Concrete Column and ring beam & slab building.				
B. Masonry Walls with concrete slab Floors & roof with : Ring Beams ? Or no Ring Beams ?				
C. Masonry walls with timber floors/roof.				
D No of floors		**Other Comment:**		
E Have you added an extra floor later or made any major changes eg removed walls/columns		State additional floors and Approx. Plan Area:		
F Age of Building		**Other Comment:**		

FOUNDATIONS			
F1 Give brief description	F11 – Are they mass concrete pads? F12 - Are they tied together with a strip footing ? F13 – Are they rubble or masonry pad/strip footings? F14 - Are the footings reinforced? F14 – State if other :	Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know?	
F2 Give approximate depths and info on ground	• Footings are on soil (S) • Footing are on rock (R) • Do not Know	**Depth** 1m 2m >2m	*Footings on* : S or R S or R S or R

F3 Record of Construction	I have photos / I do not have photos	*Comments:*

RECORD OF DAMAGE / CONSTRUCTION

D1 Did any of these vulnerable parts of the structure collapsed or partial collapsed	• Roof tiles • Staircases /landings • Parapets or balconies • Boundary walls greater than 1.5m • Water tanks on roof damaged • Water tanks below ground damaged • Parts of stone cladding fell off, if any	Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know?
D2 State Damage to other main parts of buildings	• Columns damaged • Beams/floors damaged • Stairs damaged • Walls badly damaged –gaps >10mm • Walls partially collapsed • Slabs fallen • Roofs collapsed • Outside water pipes/services broken • Front Open Canopy or veranda Damaged	Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know? Yes /No /Do not know?
D3 Record of Construction & damage	• I have photos/video of other foundation construction (see also F3) • I have photos/video of my building during construction • I have photos/video of damage after earthquake	Yes /No Yes/No Yes /No
D4 Did you build and Supervise your own Building during construction?	Yes / No	*Further Comments:*

E	Any Additional Comments you may consider would be helpful.

TABLE E2 – DAMAGE CLASSIFICATION FOLLOWING EARTHQUAKE

Types of non engineering buildings:

A Buildings of fieldstone (rubble), rural structures, adobe and clay house
B Ordinary brick, large cut-stone masonry of block construction, and half-timber buildings
C Concrete buildings and well-built wooden buildings

Classification	**Damage**	**Description**
Grade 1	Slight	Fine cracks in plaster, pieces of plaster fall
Grade 2	Moderate damage	Small cracks in walls; large pieces of plaster falls; cracks and parts of chimneys fall down
Grade 3	Heavy Damage	Large and deep cracks in walls; fall of chimneys
Grade 4	Destruction	Gaps in walls; parts of walls collapse; inner walls and infill walls of frame collapse; separate parts of buildings lose cohesion
Grade 5	Total damage	Total collapse of building

ANNEXES

ANNEX 1:
History of Earthquakes, Seismology and Geology

Annex N1 HISTORY OF EARTHQUAKE, SEISMOLOGY AND GEOLOGY

N1.1 Bhuj Earthquake

India is moving northwards at rate of about 5 cm/yr and is colliding with Nepal, China and Tibet. This process has been happening for hundreds of millions of years and other continents around the World are also being affected, see Figure N1.1.

In the past, the States of Kutch and Western India are regions that have had some of the most devastating earthquakes in the World. The region is geologically unstable and is heavily affected by structural faulting and folding. In Kutch the extent of these faults and folds are shown on the plan, Figures N1.2a and the cross sections Figure N1.7a and 1.7b.

The 26 January 2001 earthquake is thought by the Indian Institution to have occurred near the town of Lodai, while the American Institution considers it occurred at a place near Dodai. Either town is close to a major east-west direction fault called the Kachchh Mainland Fault, see Fig N1.2a . The Bhuj earthquake is considered to have occurred as a result of movement along this “compression” fault releasing massive energy to the surface. Lodai is about 20km north east of the main city, Bhuj.

The energy released by the Bhuj earthquake is one of the largest ever recorded anywhere around the world, see Figure N1.3.

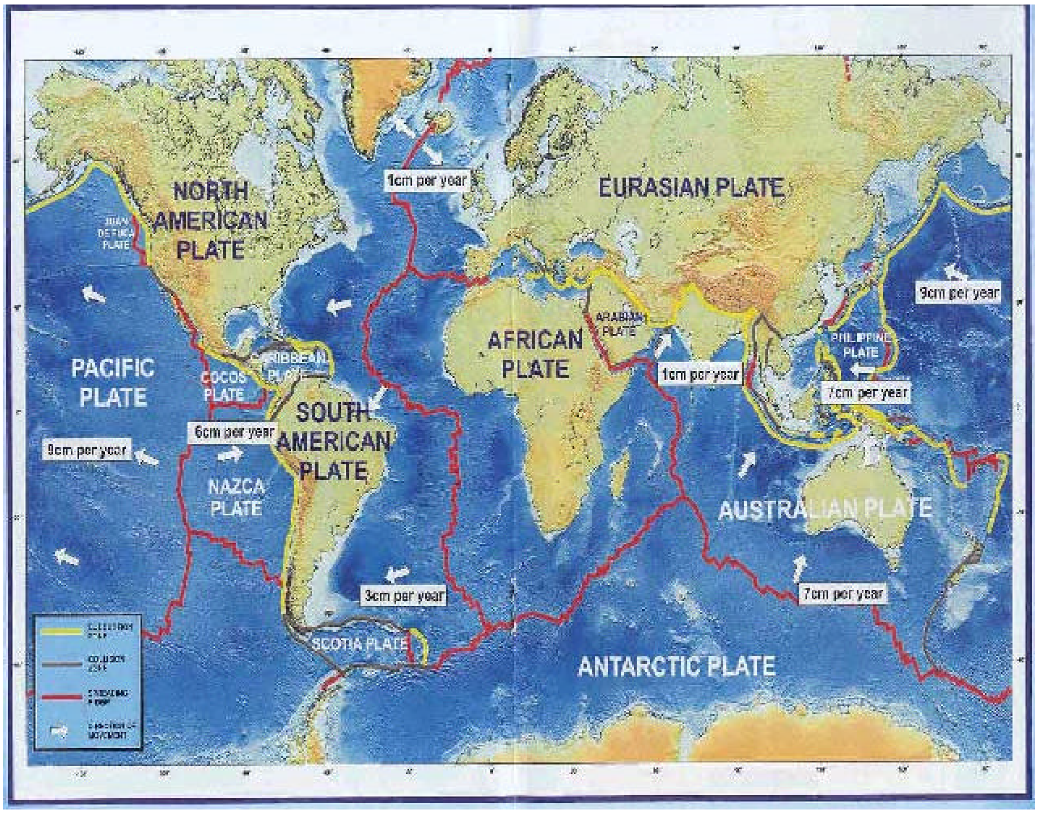


Figure N1.1: Moving Continents – yellow zones signify high earthquake zones (ref 10)

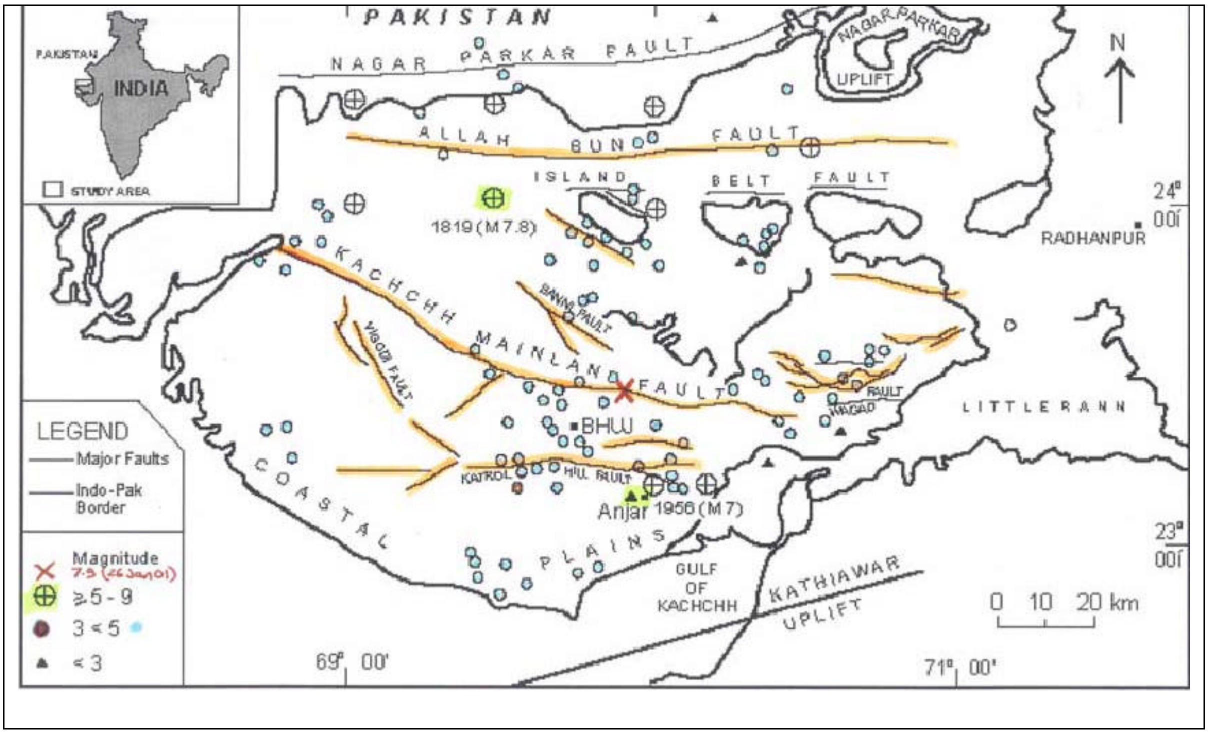
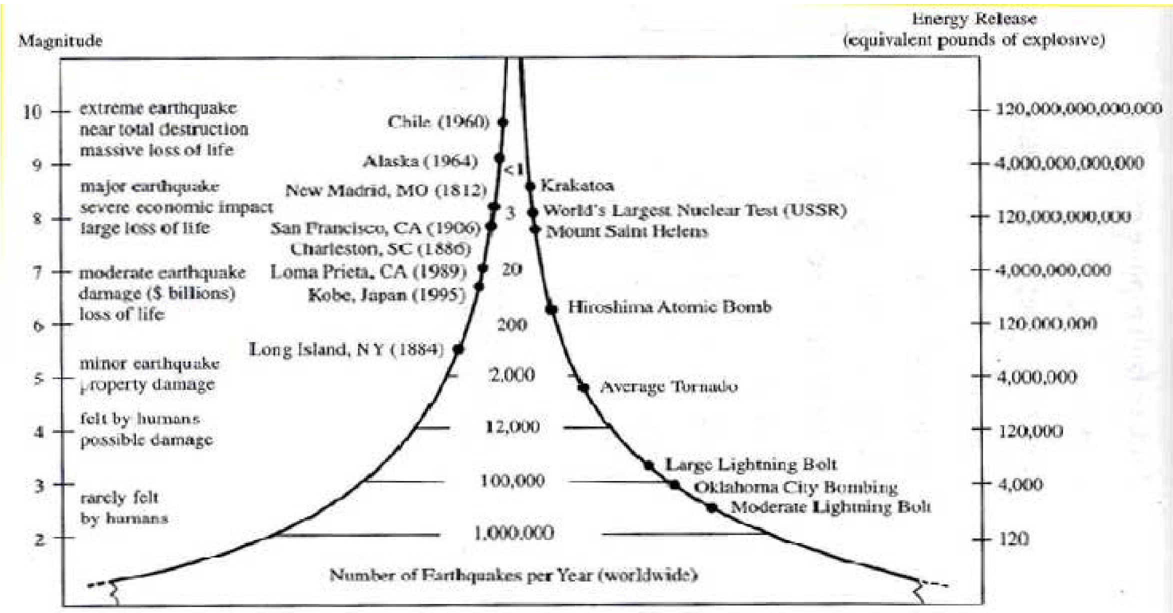


Figure N1.2a: Fault pattern and past earthquakes in the last 200yrs in Kutch

Figure N1.2b: Map of Kutch –1880 (ref 4)



Curves showing the approximate number of earthquakes a year worldwide as a function of magnitude and energy release. The energy in the Krakatoa and Mount Saint Helens eruptions is the total released in the eruption, *not* that in the accompanying earthquakes. [after IRIS]

Figure N1.3: Other earthquakes and energy realeased (Gujarat earthquake Mw = 7.9)

N1.2 Past Earthquakes in Kutch and Gujarat

The region of Kutch and Gujarat has been subject to many earthquakes in the past as shown on Figure N1.2a and Table 1 below. The previous recorded earthquake, of equivalent magnitude to the 26 January 2001 event, occurred in 1819 and resulted in a 90km rupture of the ground referred to on Figure N1.2a as the Allah Bund Fault. This resulted in the ground to the south dropping by about 4m and the low lying region of the Great Rann of Kachchh being temporarily flooded by the Arabian sea.

A more detailed catalogue of earthquakes in Gujarat / Kutch is given in Oldhams work (1869), summarised in Table 1.

Table 1: Record of Past Earthquakes in Gujarat to end of 19th century

Year	Month/Time	Town	Eye witness accounts at time
1668	May	Samaji,	Near Delta of Indus. "town sunk into ground with 30,000 house"
1684	?	Surat	Mentioned in 1852 catalogues
1819	17 June, 6.45pm to 20th	Kutch	"most severe and destructive earthquake on record in India… Bhooj…reduced to ruins, 2000 people perished….shock lasted from 2 to 3 minutes with heavy appalling noise…". Liquefaction boils" cones of sand, 6-8 ft high were thrown up." At Ahmedabad, "500 people …perished" attending a wedding feast Land dropped by 14 feet at the Allah Bund fault.
1820	27 Jan & 13 Nov	Bhooj (now called Bhuj)	"accompanied by a loud noise like thunder"
1828	20 July, 1pm	Bhooj	Tumbler of water "nearly emptied"
1843	8 Feb, 2am	Ahmedabad	"Four shocks with 8 minutes; from NS to SW,slight and local"
1845	19-25 June	Lukput, Kutch	"66 shocks, some …destructive". Land dropped and sea rolled in flooding land 40miles and "of Lukput nothing was above water"
1848	26 April	Mt Aboo	"heavy rumbling noise..from SW; Bungalow cracked, tables thrown"
1864	29 April	Ahmedabad	"several persons thrown down…shocks from NW.Felt in Surat, Mt Aboo"

In more recent times, there has been a magnitude M = 6.5 earthquake on 21 July 1956 in Anjar, Kutch which killed 156 and devastated the town for the second time since 1819. The Bhuj earthquake is 100 times more powerful than the 1956 event. In the 20th century Talwani et al (2001) reports earthquakes in Kutch as follows:

Year	Month /Time	Town	Magnitude (M)
1903	14 Jan	Great Rann	6
1904	28 April	Bhuj	4
1921	26 Oct	Great Rann	5.5
1940	31 Oct	Great Rann	5.8-6.0
1965	26 March	Great Rann	5.3
1981	26 April	Great Rann	4.1
1982	31 Jan	Great Rann	4.8
1982	18 July	Rapar	4.8
1985	7 April	Great Rann	4.4
1991	10 Sept	Great Rann	4.7
1993	2 Sept	Allah bund	4.3
1996	17 Feb	Great Rann	4.5

In summary, severe earthquakes have occurred in Gujarat, particularly Kutch, and new buildings should always be designed and constructed to resist them. Similarly, repairs and strengthening works to damaged buildings and retrofitting to upgrade seismic resistance of existing buildings are of utmost importance.

N1.3 Indian Seismic Standards and seismic zoning map.

There are a number of Indian standards for the design and construction of earthquake resistance structures and also for repairs to damaged buildings such as IS 1893-1984, IS 4326-1993, IS13935-1993, IS 13827-1993, and IS 13828:1993.

If buildings are designed and constructed to these standards, the structure may get damaged in the severest earthquakes but should not collapse. The Bureau of Indian Standards have produced a seismic map of India (see Figure N1.4) which divides the country into a number of zones in which one might reasonably expect earthquakes of past intensities to occur.

Indian Standard Seismic Zone Map, see Figure N1.4.

This map is based on considering the:

a) past history of earthquakes where magnitudes and location of earthquakes have been measured by ground instrumentation
b) maximum intensities recorded from damaged surveys when no measurements have been taken
c) faulting and folding of each region (tectonics)
d) geology of the area

In addition to this map, major towns, cities and industrial areas have been identified in the IS:1893-1984 standard for seismic design.

Bhuj, Kutch falls in the severest seismic Zone V.

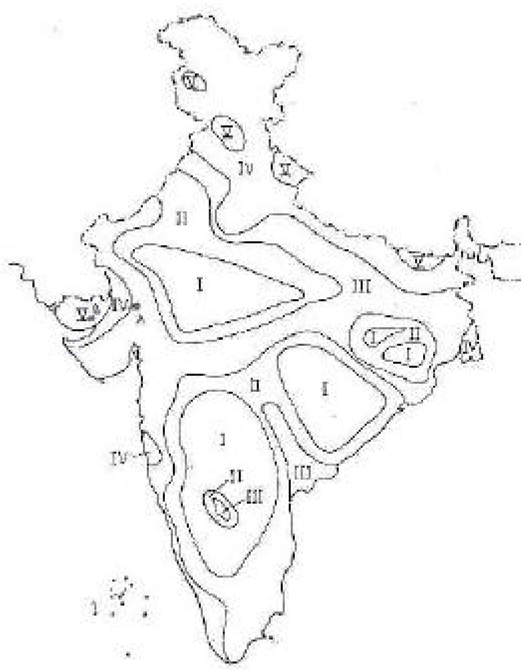


Table 19.3. Values of Basic Seismic Coefficient and Seismic Zone Factor

Serial No.	Zone No.	Basic Horizontal Seismic Coefficient* α_0	Seismic Zone Factor† F_0
1	V	0.08	0.40
2	IV	0.05	0.25
3	III	0.04	0.20
4	II	0.02	0.10
5	I	0.01	0.05

*For seismic coefficient method.
†For response spectrum method.

Figure N1.4: Indian Earthquake Standard, IS:1893-1984, updated 1987(from ref 8)

N1.4 The Geology of Gujarat

N1.4.1 The Geology of Kutch

The geology of Kutch is very complex. It may be generalised as follows, see also Figure N1.5:

- Most of Kutch outside the Great and Little Rann and the Gulf of Kutch is on high ground, generally overlain by hard volcanic rock (Basalt) or deep layers of weathered Sandstones, Shales, marls and limestone
- Other areas, for instance around the towns of Anjar are additionally underlain by clays
- Coastal and lowland areas are on water logged loose sand

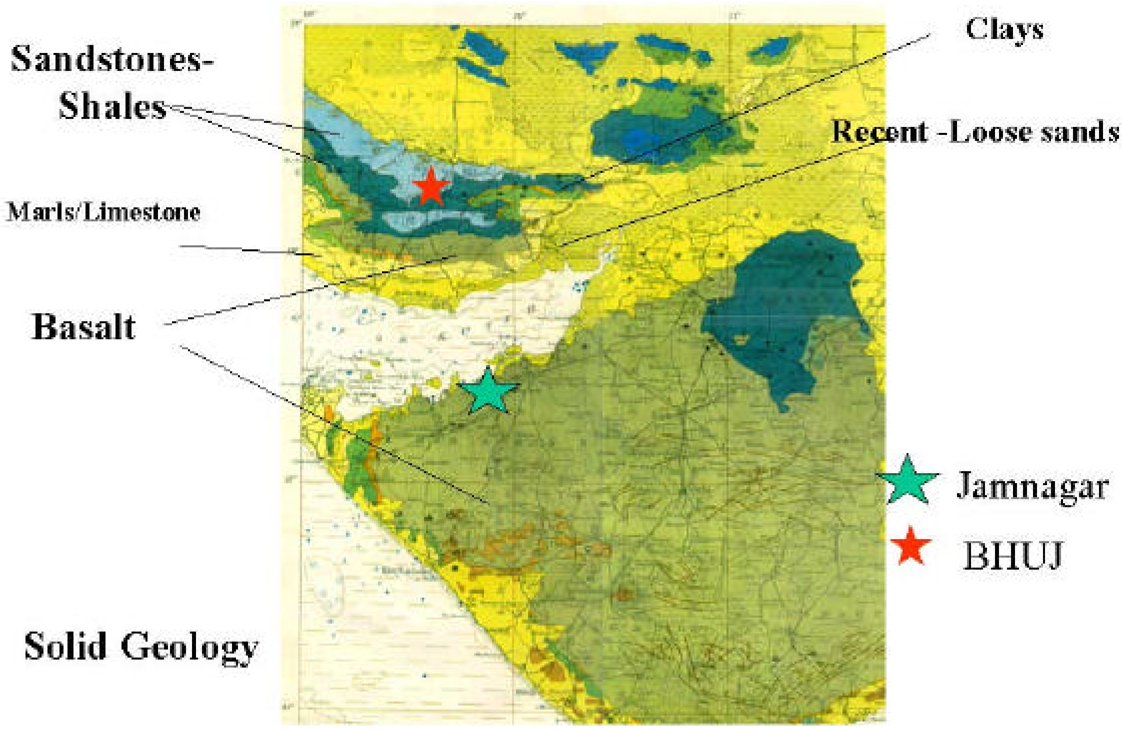


Figure N1.5: Geology of Kutch and parts of Gujarat
(extract from Geological & Mineral Atlas of India,Sheet no 23, Government of India Copyright)

The geology surrounding Bhuj and the lower plains is given on Figure N1.6. The sedimentary rocks (orange) are overlain on Bhuj Hill by Basalt (green).

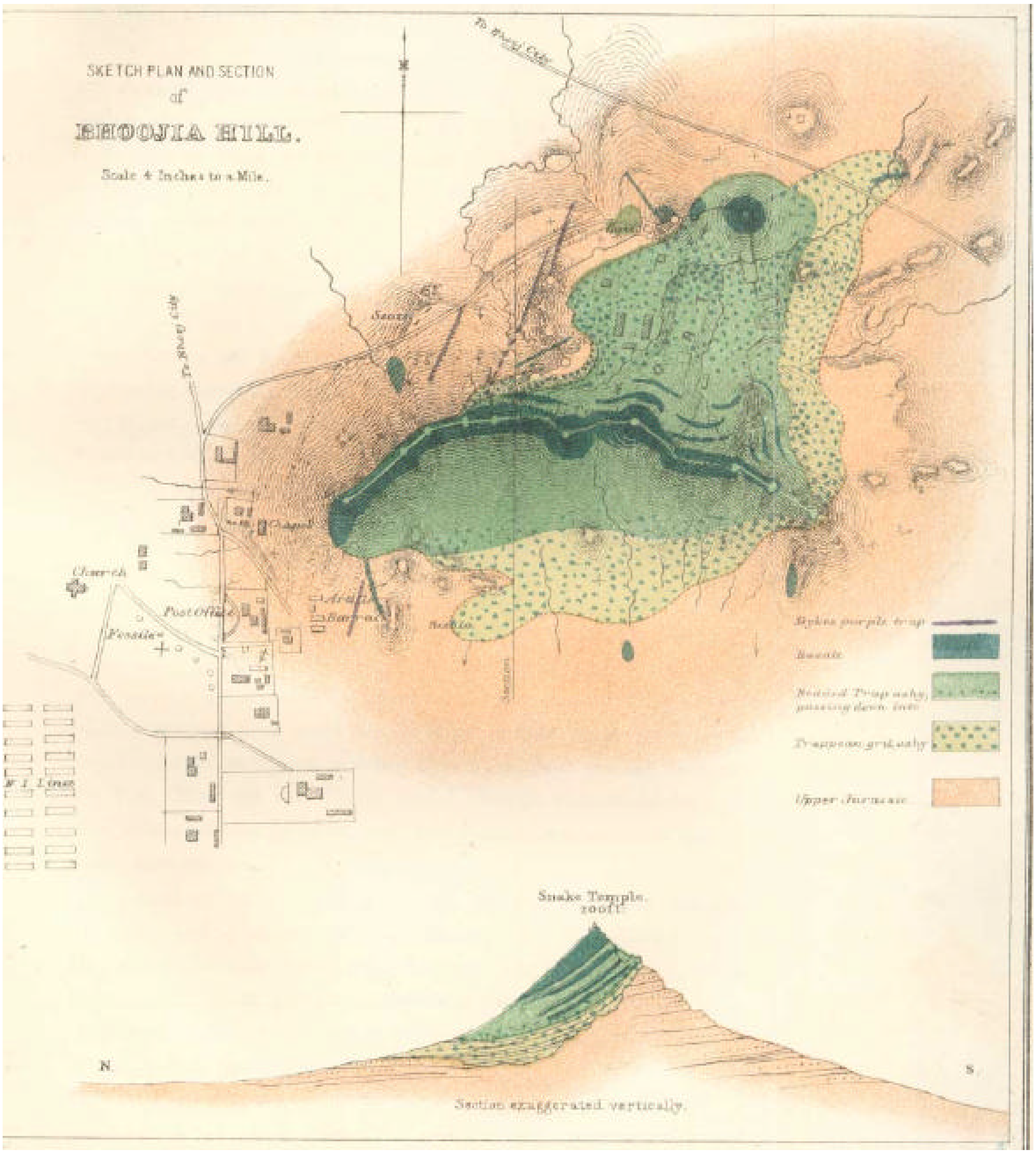


Figure N1.6: Geology of Bhuj Hill and plain (ref 4)

Part sections through the Centre of Kutch and through the Katrol Hill range are shown in Figures N1.7a and N1.7b.   High compressive stresses and tectonic movements of the earths crust in the past have caused the extensive folding of the rocks.

Figure N1.7a – Section showing structural geology through eastern part of Central Kutch (ref 4)

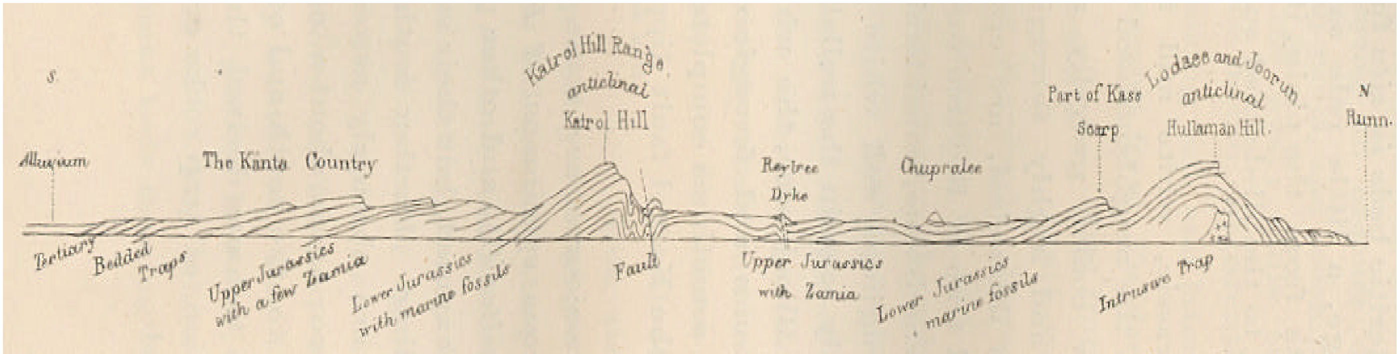
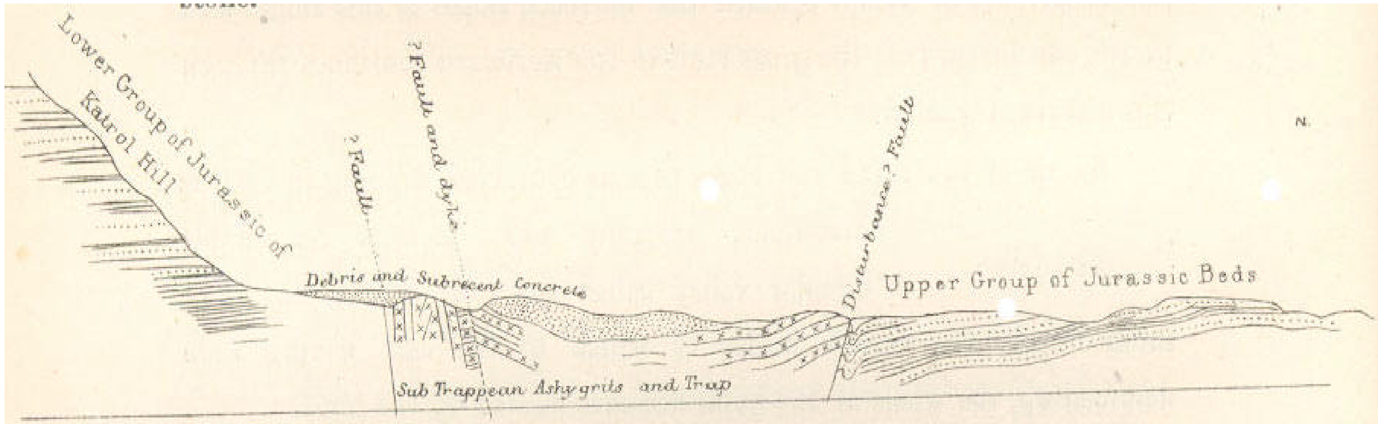


Figure N1.7b – Section showing structural geology north base of Katrol range, south of Boojoorie.



N1.4.2 Saurastra and Ahmedabad

In the Saurastra region of south Gujarat, the geology is mainly Basalt, see Figure N1.5. Limestone also outcrops west of Jamnagar. In contrast, about 250km east of Bhuj, the geology in Ahmedabad, is a deep layer of recently placed alluvial sands.

N1.4.3 The Influence of geology in earthquakes

Earthquakes release energy through the ground. The Bhuj earthquake was a shallow earthquake, considered to originate about 17 km below the ground surface near the town of Lodai. The shock waves can travel in complex ways through the earths crust before reaching the ground surface. The path of the shock waves is affected by topography and geology. In certain geological conditions, structures some distance from the epicentre can be affected more than those close to the epicentre.

In low lying areas such as the Great Rann, Little Rann, Banni Plains, Kandla River and the Gulf of Kutch, the Bhuj earthquake caused widespread “liquefaction” when the ground temporarily behaved like a liquid whilst shaken. Many structures were damaged by this event. These areas contain low lying salt flats, estuaries, intertidal zones, and young alluvial deposits (loose sands), which have a high risk of liquefaction in earthquakes.

Other problematic geological influences include:

- Buildings with shallow foundations on soft clays or loose sand.
- Buildings located on hillsides of clay or loose sand, where the hillside can fail by sliding and rotation.
- Towns located close to the edge of a steep rock face, affected by rock falls and slides

An understanding of the geology is therefore important when designing seismically resistant foundations and locating new towns which are safe from future earthquakes.

ANNEX 2:
Structural performance of buildings

N2 STRUCTURAL PERFORMANCE OF BUILDINGS DURING EARTHQUAKES

N2.1 Introduction

Experience has shown that for new buildings, the implementation of seismic construction regulations can provide a safeguard against damage from earthquakes.

For existing buildings damage will need to be evaluated and then the choice is to repair and strengthen or rebuild. Observations of the structural performance of buildings during an earthquake can identify the strong and weak aspects of their design, as well as suitable materials and construction techniques and site selection.

The study of damage is therefore an important step in designing strengthening measures for buildings.

This section contains extracts from Professor AS Arya's book, "Guidelines for earthquake resistant non-engineered construction", produced in conjunction with the International Association For Earthquake Engineering, October 1986. We would highly recommend that people from various levels read this excellent book as it contains other in depth information.

N2.2 Earthquake effects

Damage in earthquakes is caused by four basic effects:

- ground shaking
- ground failure
- tsunamis (seismic sea waves)
- fire.

Ground shaking is discussed in greater detail in this Chapter.

N2.2.1 The effect of ground shaking on structures

Inertia Forces

During an earthquake the foundation of the building moves with the ground and the superstructure and its contents shake and vibrate in an irregular manner due to the inertia of their masses (weight).

As the ground moves, say to the right, the building moves in the opposite direction relative to it (Fig N2.1), as if being pushed by an imaginary force, referred to as the 'inertia force'. The structure attempts to resist this force and in doing so absorbs the energy released. Weaker construction would provide less resistance and energy absorption and thus result in damage to the structure and in certain cases failure.

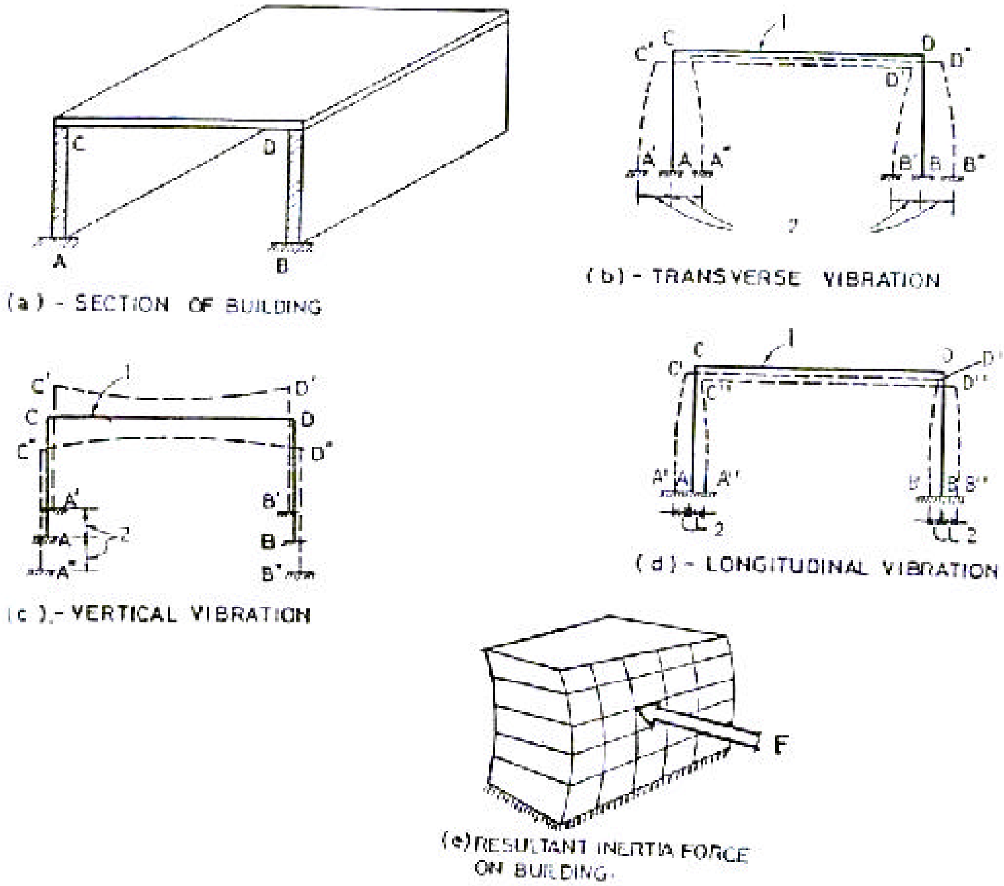


Fig N2.1 Seismic Vibrations of A Building and Resultant Earthquake Force

Seismic Loads

The process of energy transfer is complex as the ground can be moving in many directions. Thus seismic loads are reversible and occur in all directions.

In the Indian codes seismic forces are given by the following equation:

Seismic load, $F = S\ F_s\ I\ C\ W$

where,

- S earthquake zone factor
- F_s soil foundation factor
- I occupancy importance / hazard factor
- C stiffness / damping factor
- W weight of superstructure and contents

These seismic factors are explained below.

S depends on the intensity of the anticipated earthquake and is based on accelerations given on seismic zonal map.

F_s, depends on elastic period of vibration of building and the site period. It is a numerical value for site and building resonance.

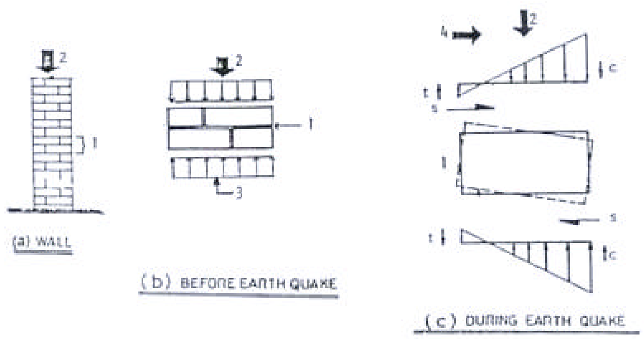
I, reflects the importance of the building and ranges from 1 for domestic building to 1.5 for important service and community buildings.

C, depends on stiffness and damping characteristics of the building. Damping is the energy dissipation property of the building; the larger the damping, the smaller the value of C. This value is dependent on the ductility of the building. Factor C ranges from 1 for buildings designed as moment resisting frames to 1.6 for those designed as vertical semi- frames relying on shear walls to resist horizontal seismic forces.

Seismic Stresses

In the same way that seismic loads are reversible so are the induced seismic stresses. Structural walls, beams and columns, normally support only vertical loads. During an earthquake, these elements experience additional vertical and horizontal loads and bending and shear stresses.

When tension from seismic bending exceeds static vertical compression, net tensile stresses develop. In the case of materials that are weak in tension, such as rubble masonry, cracking can occur, reducing the area available for resisting bending and shear (Fig. N2.2).



1 - wall element 2 – vertical load 3 – reaction stress 4 – earthquake force
c – compressive stress t – tensile stress s – shear stress

Fig N2.2 Stress Condition in a Wall Element

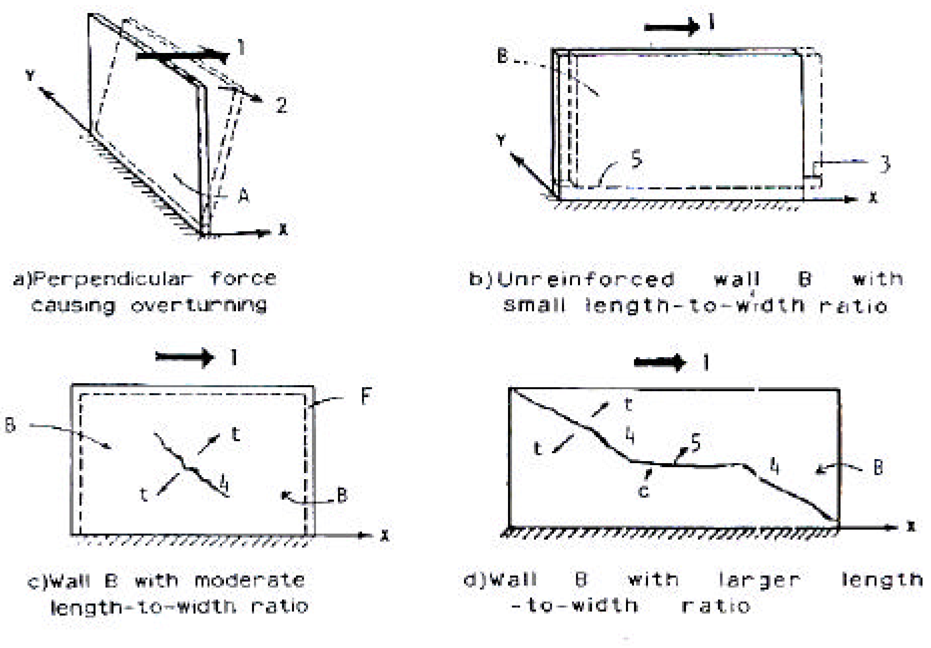
N2.3 Failure mechanisms of structures

N2.3.1 Free Standing Masonry Walls

Freestanding walls have very little resistance to seismic loads. These walls experience two types of forces in earthquakes, see Fig N2.3

a. Out of Plane Force: The force acting on the mass of the wall tries to overturn it. The seismic resistance of the wall is minimal due to the low tensile strength of the mortar (Fig N2.3a)

b. In Plane Force: The wall offers greater resistance in this direction by virtue of large length to width ratio. During an earthquake, the seismic force in this direction may cause damage in the wall panel as shown in Fig N2.3c and d, but may not collapse. In this case the unreinforced masonry wall, although not designed as a shear wall, acts like one provided it helps in preventing collapse of the structure.



A – wall A B – wall B F – framed

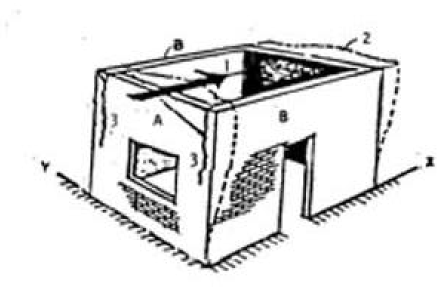
1 – earthquake Force 2 – overturning 3 – sliding 4 – diagonal cracking
5 – horizontal cracking

Fig N2.3 Failure Mechanism of Free Standing Walls

N2.3.2 Wall Enclosures without Roofs (eg typically Courtyards)

A walled enclosure is shown in Fig N2.4. For force in direction X, Walls B may act as an unreinforced "shear wall". The wall panel A acts as a vertical element supported on two vertical sides and at its the base.

Near its vertical edges, Wall A will carry reversible bending moments in the horizontal plane. Cracking and separation of the wall may occur along these edges, particularly as these corners generally have weak vertical joints. Failure of the corners can lead to collapse of the wall or severe weakening of the enclosure.



1 – earthquake force 2 – bending of wall A 3 – bending cracks at ends of wall A

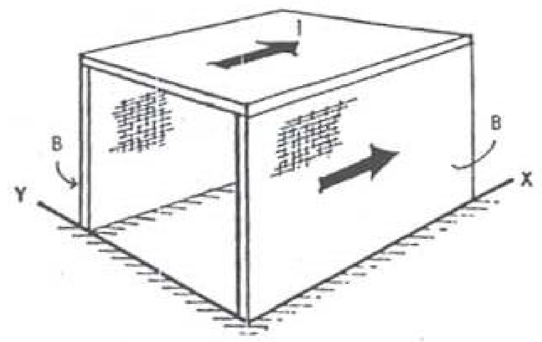
Fig N2.4 Failure Mechanism of Walled Enclosure Without Roof

N2.3.3 Walled Enclosures with Roofs and Floors

The addition of concrete floor or roof slabs to a walled enclosure provides diaphragm action, capable of transferring the inertia forces to the walls.

In the case of timber roof and floors adequate ties are required between the wall and roof / floor to transfer these loads to the walls.

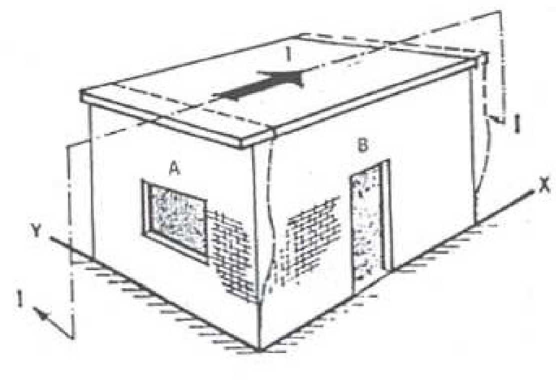
a. A roof and floor concrete slab on two walls (Fig N2.5) is strong for in-plane forces but is still weak for out of plane forces.



1 – earthquake force B – wall B

Fig N2.5 Roof on Two Walls

b. A concrete slab on a walled enclosure (Fig. N2.6) provides better resistance against both in-plane and out-of-plane forces as it acts as a rigid box in both directions and provided the slab overhangs beyond the outer face of the walls. However, its strength is limited by the length of enclosure and number of openings for doors and windows.



1 – earthquake force A – wall A B – wall B

Fig N2.6 Walled Enclosure

Flat and rigid roofs and floors bonded or tied to the masonry, provide greater resistance to seismic forces provided they are cast directly over masonry walls and embedded into the walls.

Roofs and floors that simply rest on masonry walls, for example precast slabs or timber joists, will offer limited resistance through friction at wall and slab interface during an earthquake. These may not be adequate in an intense earthquake.

It is essential that walls are adequately tied to roof and floors to prevent relative displacement of the walls, which could bring down the structure. Some examples of good anchorage between roof and walls are given in Figs N2.7 and N2.8.

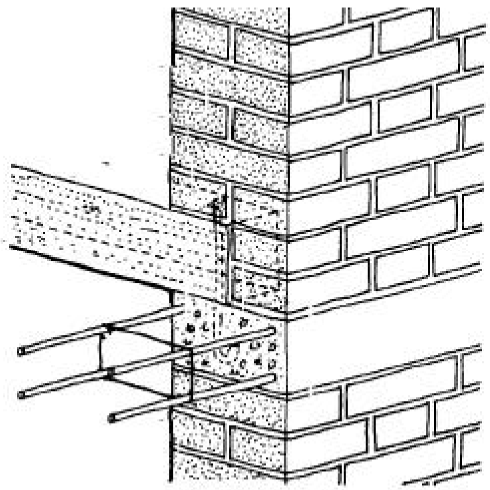


Fig N2.7: Anchorage of timber floor to concrete ring beam(or use bent metal straps if holes cannot be drilled)

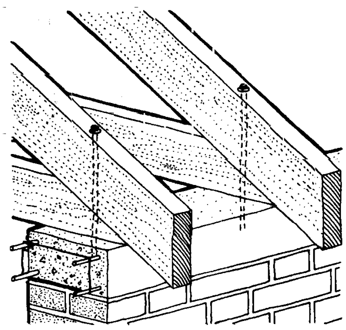


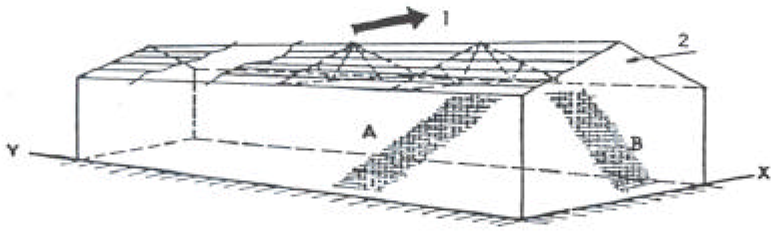
Fig N2.8: Anchorage of roof to ring beam (if holes cannot be drilled use bent metal straps)

N2.3.4 Long Buildings with Roof Trusses (eg Schools, Public Buildings, Warehouses)

In such buildings the trusses rest on the walls. In Figure N2.9, for ground motion along the X–axis, the inertia force is transmitted to Wall A as an out of plane lateral load. This force may cause the roof trusses to slide on the walls unless anchored by bolts through a ring beam.

Wall A could collapse under the action of the out of plane force, unless the roof is adequately braced (horizontally) to transfer the forces through the bracing and into the gable Walls B. The roof bracing will limit bending in Wall A. Use of gable and roof bands to provide horizontal confinement is also important as detailed in Appendix B.

For ground motion in the Y direction, Walls A will now act as unreinforced “shear walls”. However, the weak gable triangle will attract inertial forces and may collapse unless gable bands and adequate roof bracings are detailed around the triangle, or a hipped roof is used.



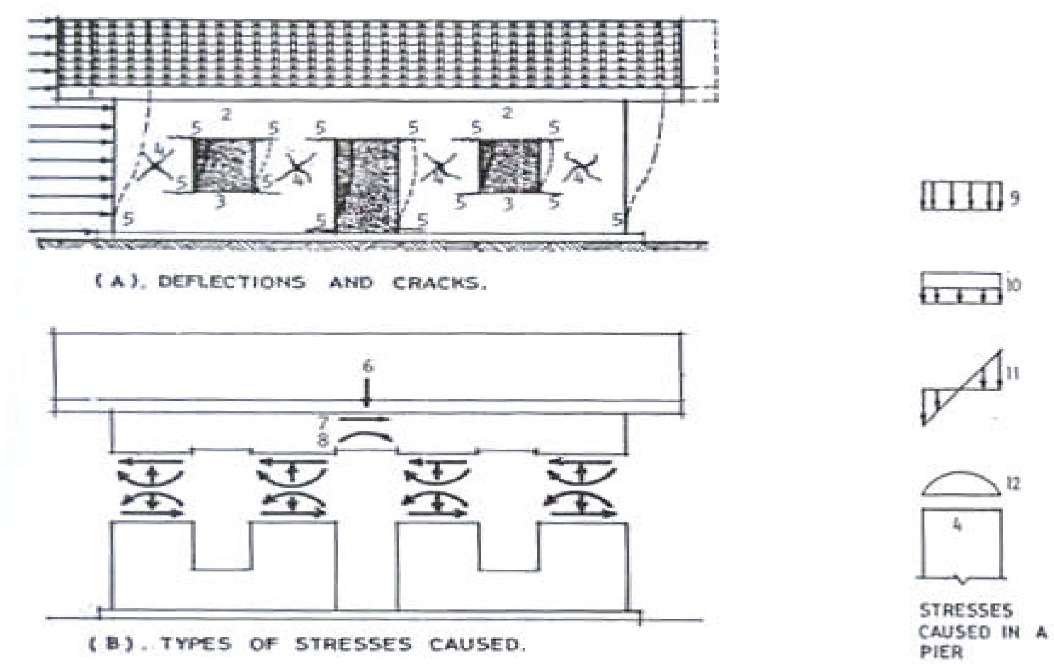
1 – earthquake force 2 – gable end A – wall A B – wall B

Figure N2.9 Long building with roof trusses

N2.3.5 Shear Walls With Openings

Properly designed shear walls form the main lateral earthquake resisting elements in many buildings. Reference to Fig.N2.10 shows a typical wall with window and door openings. The piers between the openings are more flexible than the portion of the wall below (sill) or above (spandrel) the openings. The wall is likely to deflect as shown, with maximum movement occurring at roof level.

The wall sections at the top and bottom of the opening attract greatest tension and compression, whilst at mid-height the masonry piers carry maximum shear.



1 – Earthquake force   2 – Spandrel masonry   3 – Sill masonry   4 – Pier, critical section for shear
5 – Critical section for bending   6 – Vertical load   7 – Horizontal force   8 – Overturning moment
9 – Axial stress due to vertical load   10 – Stress due to moment 8   11 – Bending stress due to force 7
12 – Shear stress due to force 7.

Figure N2.10 Deformation of wall with openings

N2.4 General concepts of earthquake resistant design

N2.4.1 Introduction

The design and construction of many common low rise buildings lacks basic resistance to earthquake forces.

In most cases, adequate resistance can be achieved by following simple inexpensive principles of good structural design and construction. Using these rules will not prevent all damage in moderate to large earthquakes, but life-threatening collapses should be avoided, and damage limited to repairable proportions.

These principles can be categorized as follows:

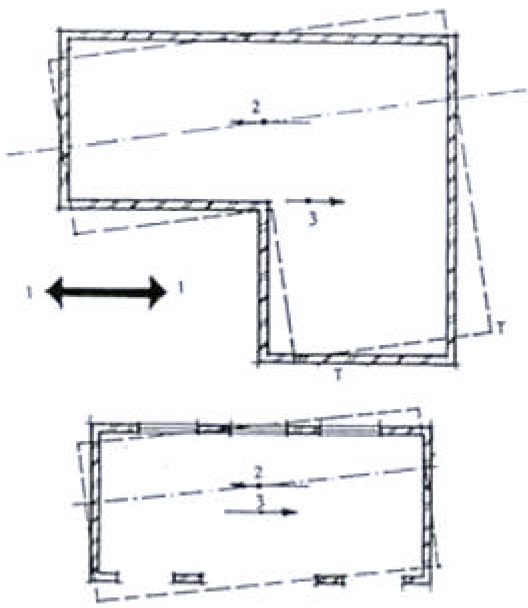
1. planning and layout of the building with consideration of the location of internal wall openings and number of storeys and foundation type.

2. structural design with special attention to lateral resistance provisions

N2.4.2 Planning and Design Aspects

Plan of Building

a. <u>Symmetry:</u> The building as a whole should be kept symmetrical about both axis to avoid torsion happening. If the building is divided into parts by moment joints each part should be symmetrical in itself. Asymmetry would lead to damaging torsion during earthquakes. Symmetry is also desirable in the placing and sizing of door and window openings (see Fig N2.11)



1 – earthquake force   2 – centre of plan area   3 – centre of gravity/inertia forces   T – twisted building

Fig. N2.11   Torsion on Unsymmetrical Plans

b. <u>Regularity:</u> Simple regular shapes behave better than ones with many projections (Fig N2.12). Torsional effects of ground motion are pronounced in long narrow rectangular blocks. To avoid this it is desirable to restrict the length of blocks to three times its width.

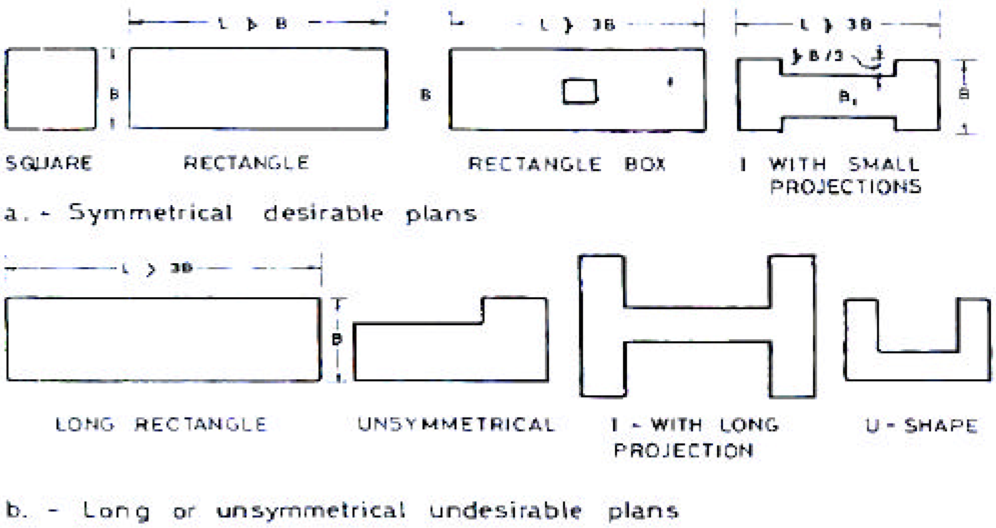


Fig. N2.12   Desired Plan Shapes

c. Separation of Blocks: If a long building is required, or one with a complex shape, two separate structural blocks with separation between should be used (see Fig N2.13). Separation gaps of about 30mm for buildings up to 2-3 storeys is considered adequate to prevent buildings clashing during earthquake shaking..

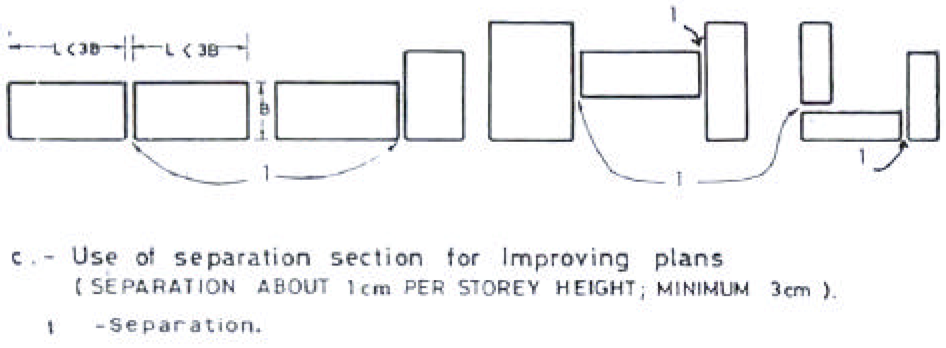
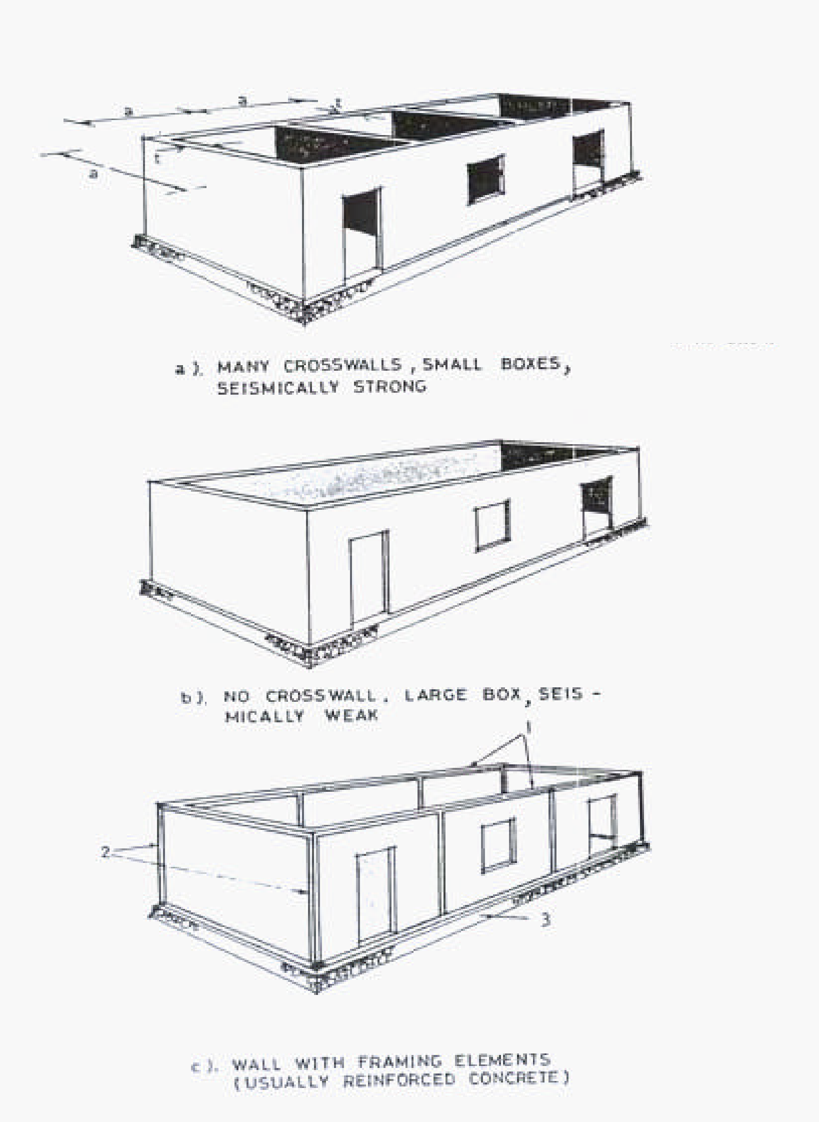


Fig. N2.13 Separation of Building Blocks

d. Simplicity: Avoid large cantilever projections, fascia stones or ornamentation involving large cornices. However, if this is not possible then these features should be designed for a seismic coefficient of 5 times the seismic intensity.

e. Enclosed Area: Have separately enclosed rooms rather than one long room (see Fig N2.14). For unframed walls limit the ratio of wall spacing to thickness, a/t to 25. Otherwise introduce framing elements.



For t thickness of walls, a should be such that a/t = 25. Otherwise framing be used as shown at c below

1 – collar beam 2 – column or buttress 3 – foundation

4 – seismic lintel /cill bands not shown

Fig.N2.14 Enclosed Area Forming Box Units

f. Choice of Site:

- Avoid sloping sites liable to slide during an earthquake. It is preferable to have several blocks on terraces rather than have a large block with foundations at different levels.
- Avoid sites that are likely to be prone to liquefaction during an earthquake.
- Avoid building on unstable slopes which could fail during an earthquake.

N2.4.3 Structural Design Aspects

The following parameters are most important for seismic design in addition to material properties, dynamic and load deflection characteristics:

Structural Framing

Structural framing systems consists of:

a. Concrete framed members with infill walls for lateral load resistance. Typically this may involve the frame taking 25% of the horizontal loads while the walls are designed to resist the remaining 75%.

b. Substantial rigid framed jointed beams and columns capable of resisting the lateral loads by themselves i.e. where large column and wall free spaces are required. This form of construction falls under engineered construction and is outside the scope of this Guide.

General comments

a. Ductility: This is the ability of a building to bend, sway and deform without collapse. Ductility is improved in brittle materials by the addition of reinforcing elements.

b. Distribution of Rigidity: Changes in the structural system of a building from one floor to the next increases the potential for damage, and should be avoided. Columns and shear walls should be allowed to run continuously from foundation to roof without interruptions or changes in material.

c. Opening Size: Openings in walls for doors and windows weaken the walls. Special provisions to ensure structural integrity are required where large or numerous openings are planned.

d. Foundations: Buildings designed to withstand earthquakes may sometimes fail due to inadequate foundations as a result of soil liquefaction or differential settlement of footings. Isolated footings are more susceptible than tied footings. Structures built on solid rock and firm soil fare better than buildings on soft ground. Also those built on sites with open and even topography are usually less damaged in an earthquake than those on hills and steep slopes.

   Where loose sands are saturated with water they would tend to lose their shear resistance altogether during shaking and become liquefied. Construction on liquefiable soils should be avoided.

e. Construction Quality: This is often a prime reason for building failure. Substandard materials and poor workmanship are the main problems.

N2.5 Summary requirements for structural safety

For typical domestic properties in Gujarat, the main requirements of structural safety in buildings are:

a. Walls must be effectively tied together to avoid separation at vertical joints due to ground shaking

b. Infill wall panels must be present along both axis of the building and be capable of resisting all horizontal forces transmitted to it.

c. Horizontal reinforcement in walls is required to transfer their own out of plane inertial load horizontally to adjacent infill walls. Lintel and sill bands must be used around openings and be continuous over the whole length of wall.

d. Roof and floor elements must be tied to the walls and be capable of acting as a diaphragm.

e. Trusses must be anchored to the supporting walls and have an arrangement for transferring their inertial force to the end walls.

f. Isolated footings with no ties must be avoided.

The seismic repairs and retrofitting measures necessary to meet these safety requirements are detailed in Appendices A to C.

ANNEX 3: Allowable bearing pressures

N3 Some guidance on allowable bearing pressures for shallow foundations on non-liquefiable soils

Table 3 gives a Guide to the assessment of the strength of natural clay/sand soils. Also, included is an assessment of the allowable bearing pressures for shallow foundations on natural clay or sand. These are approximate values and will need to be determined by a site investigation for foundation design. A geotechnical engineer should always advise on allowable foundation pressures as the structure may also be sensitive to total or differential settlements. Foundations also have to be designed for seismic loadings. Rock is not generally a problem for 2-storey foundation design and hence no bearing values are given.

Table 3 is only to be used in non-liquefiable ground conditions and where the water table is deep.

Table 3: Assessment of strength of natural soils (not fills or organic clays/silts)

Table 3a – Cohesive Soils (clay)

Consistency	Undrained shear strength (kN/m^2)	Field Assessment of soil strength	Typical values of allowable bearing pressure – a Guide (kN/m^2)
Very Stiff	greater than 150	Indented by thumb-nail; brittle or very tough	greater than 300
Stiff	75 – 150	Indented by thumb pressure; cannot be moulded in fingers	150 - 300
Firm	40 – 75	Moulded by strong finger pressure	75 – 150
Soft	20 –40	Moulded by light finger pressure	35 - 75

Table 3a – Cohesionless Soils (sand or gravel or both)

Consistency	SPT N value (total blows for 300mm penetration)	Field Assessment of soil strength	Typical values of allowable bearing pressure – a Guide for sand (kN/m^2)
Dense	30 – 50	High resistance to penetration by hand bar or pick axe	greater than 350
Medium Dense	10 –30	Difficult to excavate by shovel	100 - 350
Loose	4 – 10	Easily excavated by shovel; only small resistance to penetration by handle bar	40 – 100

ANNEX 4: References

1 **Indian Standards as follows:**

IS 4326: 1993	Earthquake resistant design and construction of buildings – Code of Practice.
IS 1893: 1984	Criteria for earthquake resistant design of structures
IS 13920: 1993	Ductile detailing of reinforced concrete structures subjected to seismic forces- Code of Practice
IS 13935: 1993	Repair and seismic strengthening of buildings – Guidelines
IS 456: 2000	Plain and reinforced concrete
IS 1905: 1987	Structural use of unreinforced masonry
IS 1904: 1984	Design and construction of foundations in soils
IS 13828: 1993	Guidelines for improving earthquake resistance of low strength masonry buildings
IS 13827:1993	Guidelines for improving earthquake resistance earthen buildings

2 **IAEE: 1986 -** Guidelines for earthquake resistant non-engineering construction, by The International Association for Earthquake Engineering (IAEE)

3 12WCEE2000 :

Non-Engineered construction in developing countries – An approach toward earthquake risk prediction, by Anand S Arya,

Seismic Safety in owner-builder buildings, by J Bothara, K Parajula, Arya and R Sharpe.

Techno-legal regime for earthquake risk reduction in India, by A Arya and Gupta.

4 **Memoirs of the Geological Survey of India, as follows:**

Vol 9: date 1872	Geology of Kutch, by AB Wynne and F Fedden, pages 1 – 295
Vol 19: date 1883	A catalogue of Indian Earthquakes from the earliest time to the end of AD 1869 (from AD839 to AD1869), by T Oldham.
	The thermal springs of India, by T Oldham
Vol 46: date 1920-26	The Cutch (Kachh) Earthquake of 16th June 1819 with a Revision of the Great Earthquake of 12th June 1897, by RD Oldham

5 Geological and Mineral Atlas of India, Map Sheet Nos 23 and 24, Scale 1: 1 million, Geological Survey of India, 1980 and 1978

6 **Seismological Research Letters, Volume 72, Number 3 May/June 2001:**

- The 26 January 2001 “Republic Day” Earthquake, India, by R Bilham et al, p328-335
- Tectonic Framework of the Kachchh Earthquake of 26 January 2001, P Talwani and A Gangopadhyay, p336 – 345

7 Contruzioni in Zona Sismica, by A Castellani et al

8 Chapter 19: India “Seismic design” by Sudhir K Jain, Brijesh Chandra and DK Paul

9 Malaysian publication(source unknown): Teddy Boen and Rekan

10 British Geological Society