

CHAPTER 7: STRENGTHENING BUILDINGS

Acknowledgements

For this part of the training course an important part of the text and numerous figures are directly derived from the following publications

- 1 LAEE, 'Basic Concepts of Seismic Codes', Vol.1, Oh-Okayama, Meguroko, Tokyo 152, 1980.
- 2 UNIDO, 'Building Construction under Seismic Conditions in the Balkan Region Volume 5 Repair and Strengthening of Reinforced Concrete, Stone and Brick-Masonry Buildings' UNDP/UNIDO Project RER/79/015, UNIDO, Vienna, 1983.
- 3 Boen, T., 'Detailer's Manual for Small Buildings in Seismic Areas', LAEE, 1978
- 4 Arya, A.S., 'Protection of Educational Buildings against Earthquakes', Educational Building Report 13, UNESCO, Bangkok, 1987

The use of this material is gratefully acknowledged

Introduction


Structural upgrading or retrofitting is the strengthening of buildings to increase earthquake resistance. It is an intervention that preferably is implemented as an integrated program covering entire settlement areas. It involves public measures of support and promotion of upgrading programs, but above all requires, particularly with regard to low income constructions, a high degree of dwellers' participation.

Structural upgrading has in recent years developed a wide range of basic technical measures that can give considerable protection to individual buildings. There are scores of very simple improvements to make existing buildings safer from which engineers can choose. The technology presented here can of course be applied to individual buildings. What is needed from the overall development perspective, however, are comprehensive upgrading programs.

The technology itself is quite straightforward, but can not be implemented by self-help construction unless there is close supervision in the design and execution of the construction works.

The focus here is on the upgrading of low income housing and does not take up the retrofitting problems of advanced public buildings. This training module does not address any urban development problems such as life line systems, nor does it take up any post earthquake interventions. The time constraints in in-service training do not allow that.

Community participation is a central issue in upgrading, and some basic information is included in the part on public administration. When comprehensive programs are initiated it would be advisable to include separate training programs in community participation, as for instance have been developed by UNCHS. Some of the community participation information in this program originates from the same agency.

 upgrading

SESSION 1: VULNERABILITY MAPPING AND ZONING

Topic 1.1: Vulnerability Analysis of Sites

Earthquake vulnerability of housing areas depends on two factors the earthquake proneness of the area and the structural condition of the buildings. The first factor is to be established by earth scientists and the second factor should be determined by architects and engineers.

Procedure of vulnerability analysis for architects and engineers

The following procedure is an important instrument in vulnerability analysis:

1. **Identify earthquake prone areas**
 - Data from earth scientists.
 2. **Investigation of housing areas**
 - Population density,
 - Maps of housing areas (1:10.000);
 - Classify building types (fieldwork).
 3. **Classify building condition in housing areas**
 - Quality of workmanship (fieldwork),
 - Maintenance levels (fieldwork).
 4. **Produce vulnerability maps of housing areas**
- Indicate the following data on the area map (scale 1:10.000)
- Geological data (earthquake proneness),
 - Population density,
 - Zones of main building types and their vulnerability

Data from earth scientists

Physical planners should be aware of the susceptibility of the plan area to seismic tremors. The planning of structural upgrading programs is to be preceded by the acquisition of vulnerability data on the area from competent earth scientists. The preparation of vulnerability maps includes the following steps:

- 1 Collection of regional earthquake data;
- 2 Epicentral and isoseismic maps of distribution and impact of earthquakes;
- 3 Tectonic activity review of the region and earthquake source zoning;
- 4 Collect data on intensity, acceleration, velocity and magnitude-recurrence,
- 5 Develop seismic hazard map;
- 6 Develop seismic microzonation maps and establish soil effects

To this area-vulnerability information, one can now add stability information of the buildings in the area to determine the upgrading or retrofitting measures necessary for each structure

? a. which authorities in your country will have to be approached in order to acquire the necessary vulnerability data ?

key earthquake vulnerability analysis, earthquake vulnerability mapping.

Topic 1.2: Mapping Vulnerability of Buildings

The information of the earthquake proneness of a location has to be matched with information on the vulnerability of individual buildings in the area.

Two aspects of the stability of buildings are to be established the construction type and the condition of the structure. The two factors together determine the strength and resistance of the building

This building information is to be coded on the area map for each structure so that a priority classification can be made for upgrading programs.

Structure types

The following types of structure are distinguished.

- Unstabilized earth structures (adobe, sun-dried blocks, rammed earth structures)
- Masoned structures (bricks, stabilized bricks, concrete blocks)
- Reinforced concrete buildings (column and slab)

- Steel frame and concrete slab buildings
- Timber structures
- timber frame structures with earth fill in
- timber houses
- Bamboo structures

Building condition

The condition of the building should also be determined

- Quality of workmanship,
- Maintenance condition

For the relation between earthquake effects and the design and strengthening of buildings see topic 3 2



earthquake vulnerability mapping

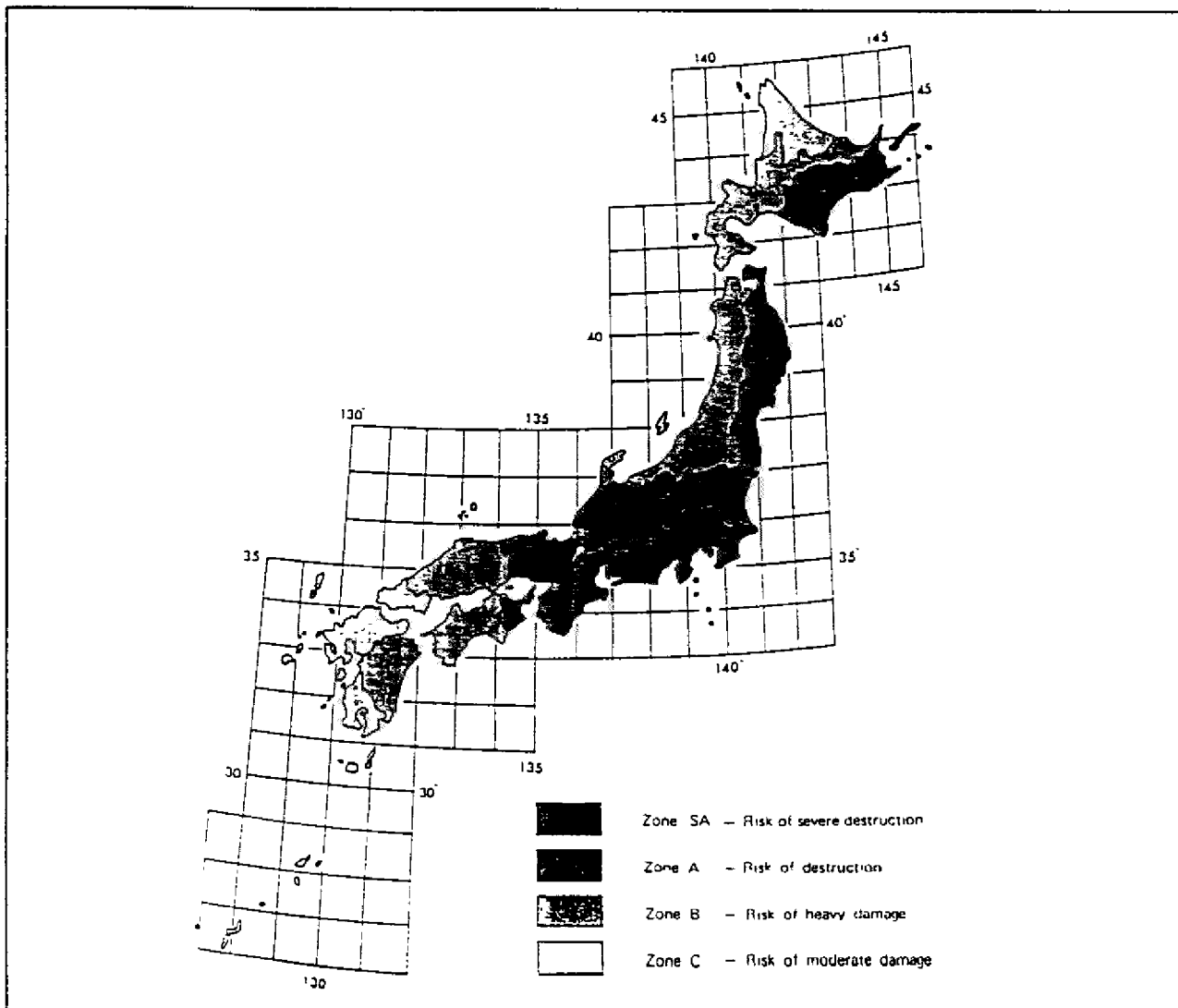


Figure 1.1-1 Seismic Zone Map of Japan [5]

SESSION 2: SEISMIC EFFECTS ON STRUCTURES

Topic 2.1: Seismic Effects on Structures

Earthquakes create horizontal and vertical forces on structures. An earthquake results in vibration of the building along the three axes.

The action is schematically shown in Figure 2.1-1. The following main points are important

- 1 The whole building and its contents, are shaken.
- 2 The movement reverses in direction. There could be a number of reversals each second, the number of cycles per second depends on the characteristics of earthquake and the structure.
- 3 Forces on the building are created by ground movements. These are proportional to the mass of the structure. The lighter the material, the smaller the force. The mass of materials is thus an important property.
- 4 Additional vertical loads are applied to beams, columns, cantilevers due to vertical vibrations. As the forces reverse so the effective load is sequentially increased and decreased.
- 5 The supporting members, walls and columns, carrying only vertical loads before the earthquake, now have to carry horizontal bending and shearing effects as well. The stress condition changes from one of compression to that of compression, bending and shearing combined as shown in Figure 2.1-2. When the bending effect due to earthquake exceeds the vertical compression, net tensile stress will occur. If the construction material is weak in tension -like stone masonry or brickwork-cracking occurs which reduces the effective

area that resists horizontal shear. When the shearing resistance of the material is exceeded, sliding of material occurs, cracks become wider, walls bulge and portions move out, leaving gaps. The strength of materials used, not only in compression but in tension and shear also, is important for earthquake resistance.

- 6 Damping of the building system has the effect of reducing the movement of mass. The higher the damping, the greater the reduction.
- 7 The dynamic response and damage behavior of a building is a function of the stiffness, strength and ductility characteristics of the structural elements resisting the earthquake forces. This can be represented by reversible load vs displacement diagram of the elements, from zero to the ultimate failure load.
- 8 The dynamic response represented by the Response Spectra indicate clearly that for stiff, short-period buildings, such as in low height constructions, the effective acceleration may be much larger than peak ground acceleration, and some damage is inevitable. If the building has a plateau of resistance, that is ductile deformation capability, there is a good chance of the building surviving the earthquake with moderate damage.

It is thus seen that the following properties and characteristics are most important from the seismic view point.

- 1 Material Properties
 - Strength in compression, tension and shear including dynamic effects
 - Unit weight

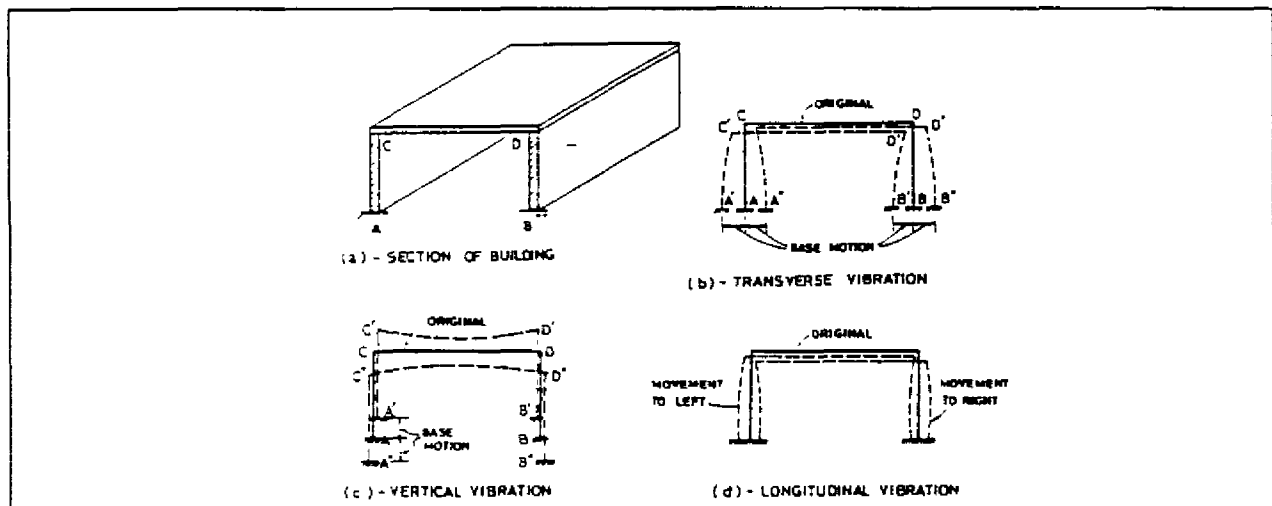


Figure 2.1-1 Seismic Vibrations of a Building

- Modulus of elasticity.
- 2. Damping and ductility in the system
- 3. Load-deflection characteristics of building components

Seismic effects, seismic vibrations.

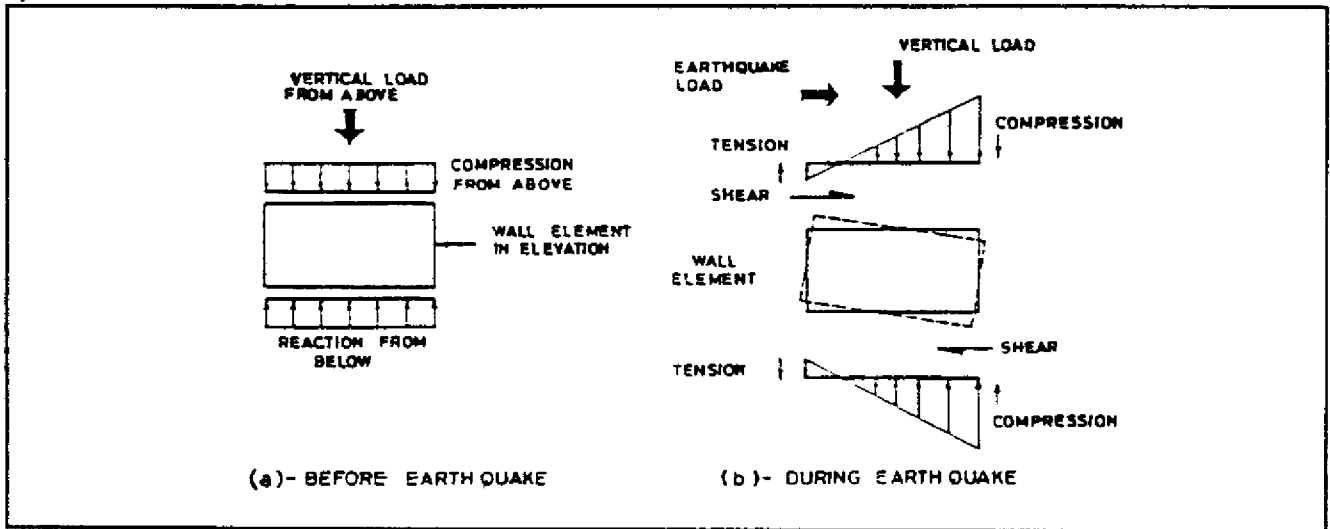


Figure 2.1-2 Stress Condition in Wall Element

SESSION 3: GENERAL DESIGN ASPECTS

Topic 3.1: General Design Aspects

Earthquakes do not respect complicated theories and calculations, division of responsibilities or geographic boundaries. Simplicity, regularity and symmetry of building form and configuration, and the quality of construction are the important factors.

A good configuration and structural form increases the resistance of the building, simplifies the design and construction and reduces the cost of providing earthquake resistance.

Some of the major problems relating to earthquake design are created by the original design concept chosen by the architect. Nothing within the power of structural engineer can make a badly conceived building into a good earthquake resistant structure.

Plan and Elevation of Buildings

Symmetry: The building as a whole or its various blocks should be kept symmetrical about both axes. Asymmetry leads to torsion during earthquakes and is dangerous (Figure 3.1-1, undesirable plans). Symmetry is also desirable in the distribution of openings.

Rectangularity: Rectangular plans behave better in earthquakes than others. Torsional effects of ground motion are increased in long narrow rectangular blocks. Therefore, it is desirable to limit the length of a block to three times its width. If longer lengths are required, two separate blocks with sufficient separation between should be provided (Figure 3.1-1, use of separations).

Separation of Blocks: Separation of a large building into several blocks may be required so as to obtain symmetry

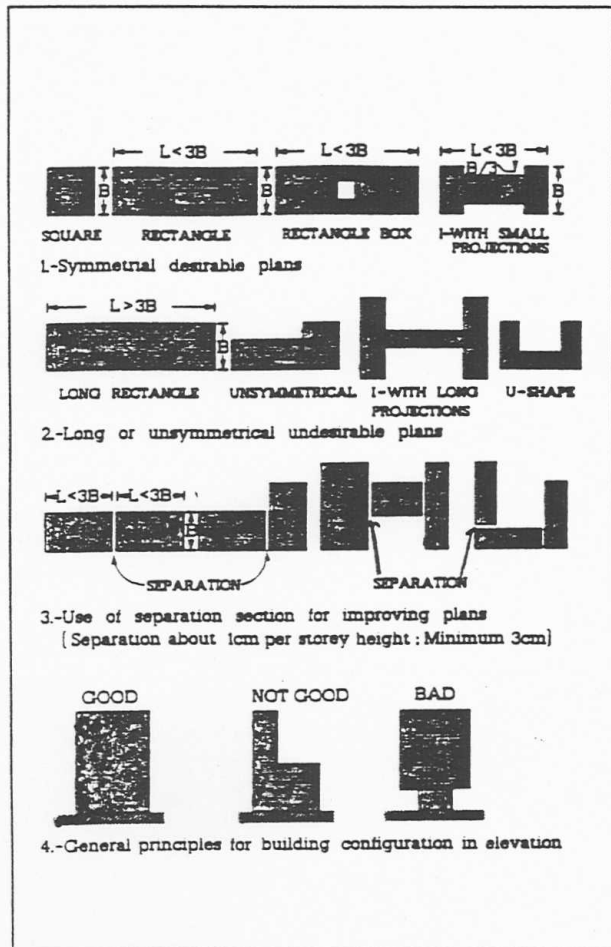


Figure 3.1-1 Plans, shapes of Building Blocks [1]

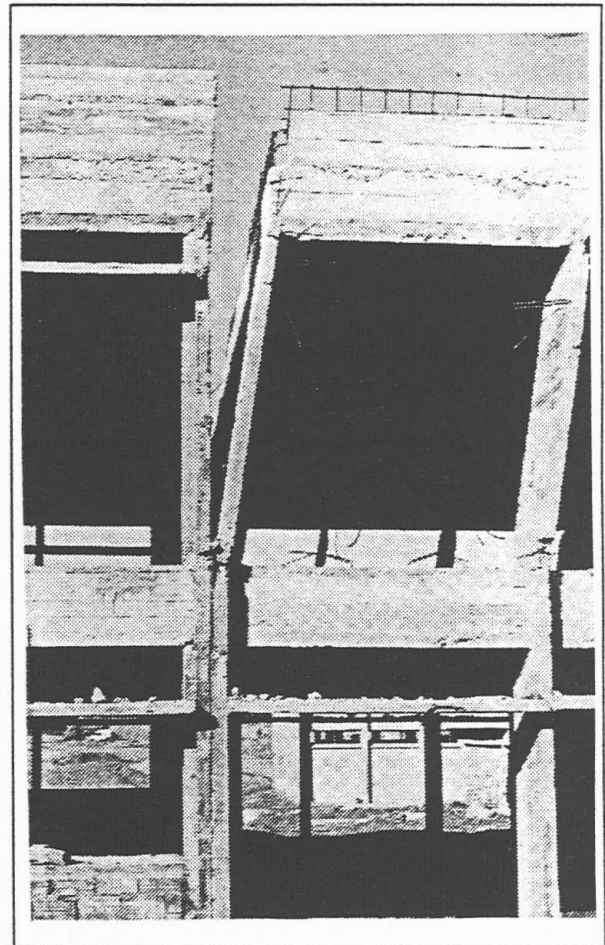


Figure 3.1-1a A building separated by an expansion joint but not by an adequate gap was probably damaged because of interaction between the two sections.

and rectangularity of each block. To prevent hammering or pounding damage between blocks a physical separation of 3 to 4 cm is adequate (Figure 3.1-1, use of separations). The separation section can be treated just like an expansion joint and may be filled with a very weak material that crumbles during an earthquake.

Simplicity: Ornaments with large cornices, vertical or horizontal cantilever projections, fascia stones and the like are dangerous. Simplicity is the best approach. Ornaments must be reinforced with steel embedded into the main structure of the building.

Note: If designed, a seismic coefficient about 3 times the coefficient used for designing the main structure should be used for cantilever ornamentation.

Enclosed Area. a small building enclosure with properly interconnected walls acts like a rigid box. Therefore, structurally it is better to have separate square rooms

instead of a long barrack (Figure 3.1-2)

The spacing between cross walls for unframed walls of 20 cm thickness or more should not exceed 5 meters. For larger panels or thinner walls, framing elements should be introduced as shown at Figure 3.1-2c.

Separate Buildings for Different functions In view of the difference in importance of hospitals, schools, assembly halls, residences, communication and security buildings, etc., it may be economical to plan separate blocks for different functions so as to save on strengthening costs

Choice of Site

The choice of site from the seismic point of view mainly concerns the stability of the ground. The following aspects are important

Stability of Slope: Hill side slopes liable to slide during an earthquake should be avoided and only stable slopes

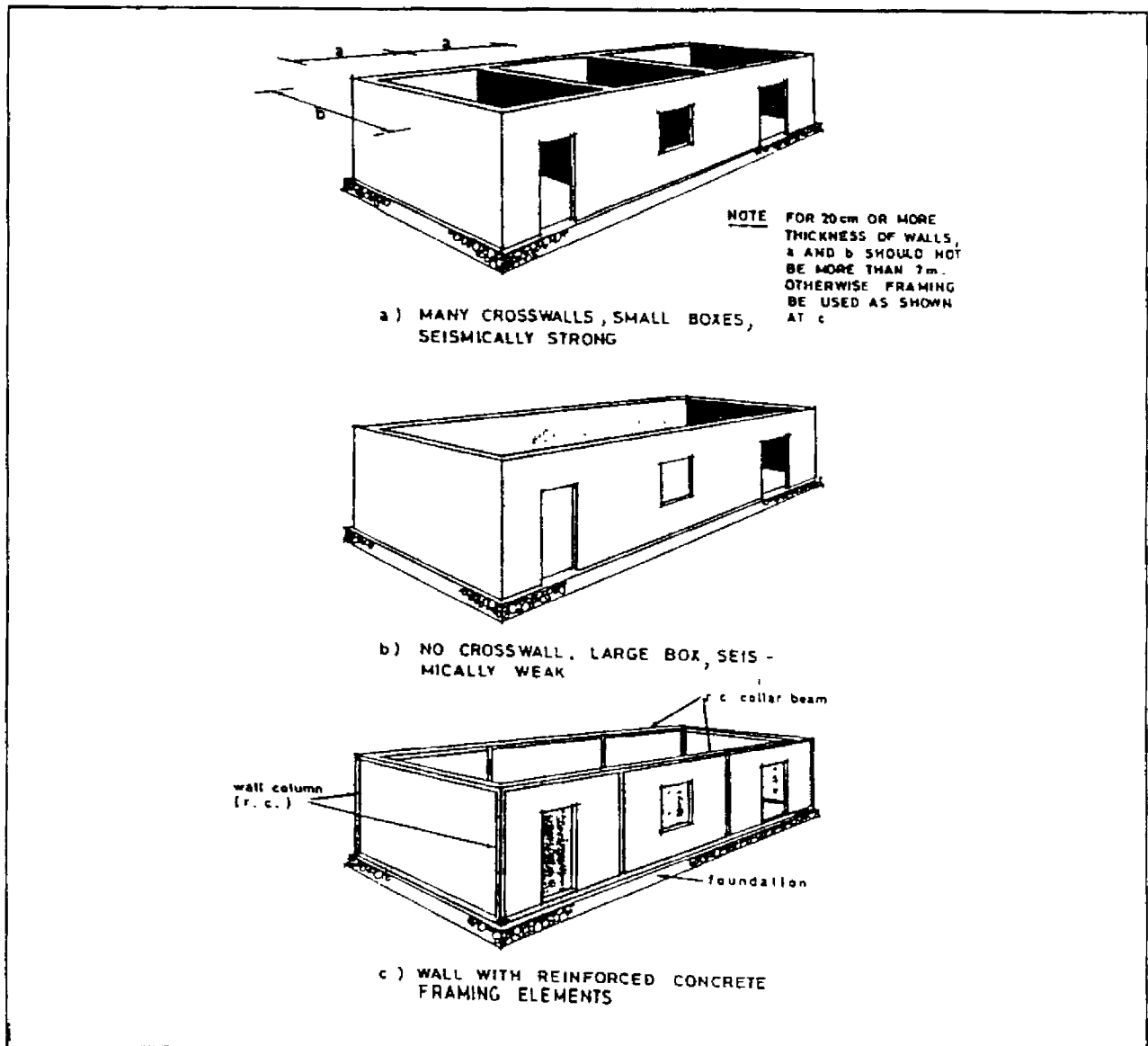


Figure 3.1-2 Enclosed Area forming Box Units [1]

should be chosen for buildings. It is better to have several blocks on terraces than to have only one large block with footings at different heights (Figure 3.1-3) Sites subject to rock falls have to be avoided

Very Loose Sands or Sensitive Clays. These two types of soils are liable to be disturbed by the earthquake so much as to lose their original structure and thereby undergo compaction. This can result in large unequal settlements which can damage a building

If loose soils are saturated with water they are apt to lose their shear resistance altogether during shaking and become liquefied. Although such soils can be compacted, for small buildings the operation may be too costly and is better avoided. For large building complexes, such as villages, this factor should be investigated and addressed. A stable site with forcing bars at critical sections as indicated in other data sheets.

Fire Resistance

It is not unusual during earthquakes that, due to snapping of electrical fittings, short circuiting takes places, or gas pipes may develop leaks and catch fire. Fire can also be

started due sufficient bearing capacity should be chosen and its drainage condition should be such that no water accumulates and saturates the ground around the foundations.

Structural Design

Ductility is a desirable quality for good earthquake performance and can be incorporated, to some extent in otherwise brittle masonry constructions, by introduction of steel reinforcement to kerosene lamps and kitchen fires. Fire sometimes can even be more serious than earthquake damage. Buildings should therefore be preferably constructed of fire resistant materials

- ? a Which shapes of low rise buildings are hazardous ?
- b Which is the most common weakness in configuration of local buildings ?
- c. What can be proposed when a very long building has to be made earthquake resistant ?

Key Seismic design, building blocks, stability of slopes

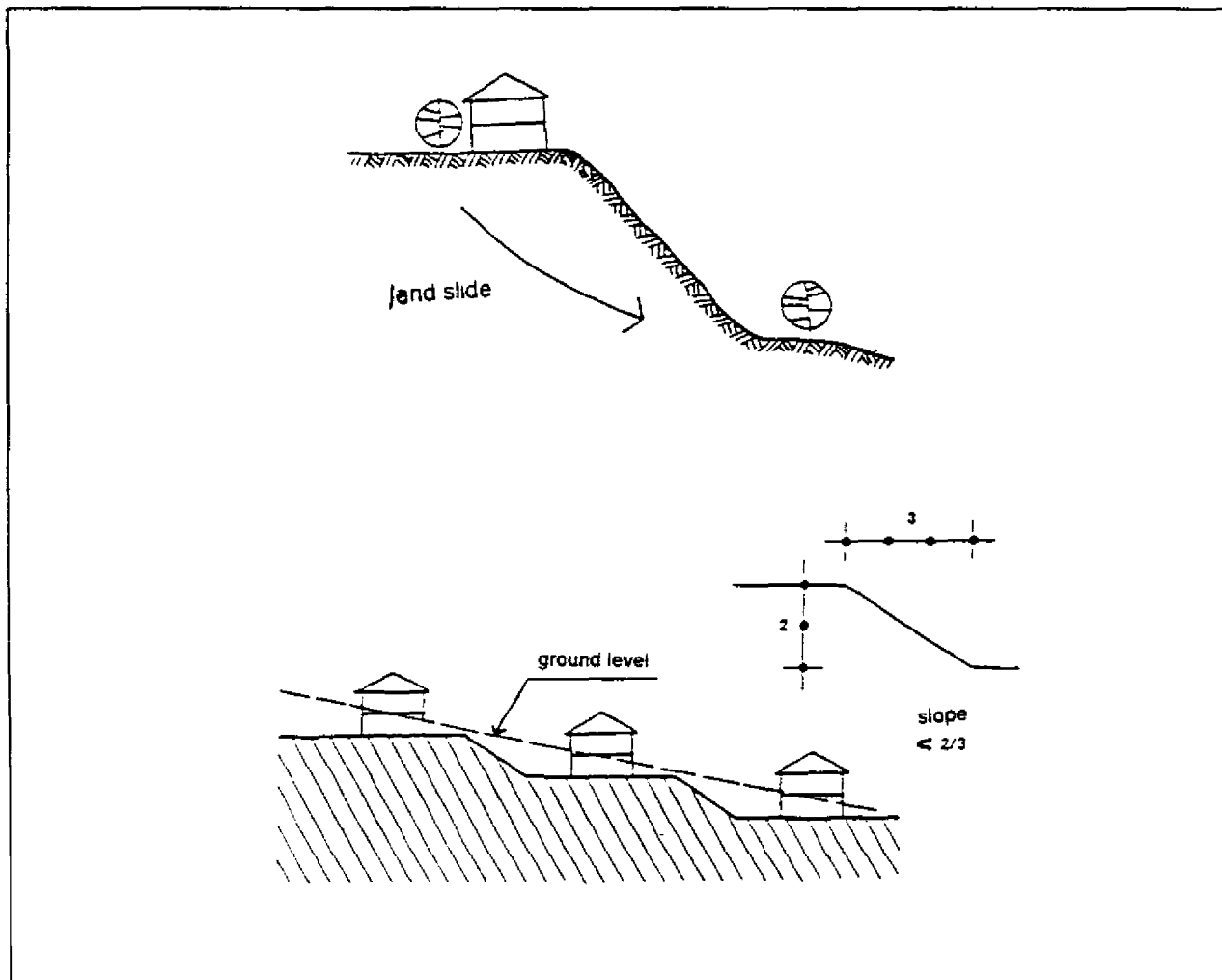


Figure 3.1-3 Stability of Slopes [6]

Topic 3.2 : Earthquake effects related to design considerations

Effects

Earthquake effects can be assessed by different scales, such as Modified Mercalli Intensity (MM) Scale, Medvedev-Sponhever-Karnik (MSK) Scale or the European Macroseismic Scale 1992 (EM-92). These describe the effects of earthquakes in 12 steps. The description of the steps (according to EM-92) and the relation to the earthquake magnitude (according to the scale of Richter) are presented in Table 3.2-1.

EM-92	Intensity Scale	Earthquake Magnitude and MM	
		Magnitude (Richter)	Intensity (EM-92)
I.	Not Felt		
II.	Scarcely Felt		
III.	Weak		
IV.	Largely observed	4.0 - 4.9	IV - V
V.	Strong	5.0 - 5.9	VI - VII
VI.	Slightly Damaging	6.0 - 6.9	VII - VIII
VII.	Damaging	7.0 - 7.9	IX - X
VIII.	Heavily Damaging	8.0 - 8.9	XI - XII
IX.	Destructive		
X.	Very Destructive		
XI.	Devastating		
XII.	Completely Devastating		

Table 3.2-1

From the 12-step intensity scale can be concluded that little or no damage is to be expected for the intensities I to VI. The last three intensities indicate a heavy destruction risk for non-engineered buildings. For the intensities VII to XI measures for improving earthquake resistance (at reasonable cost) may be considered.

Seismic Zones

For building design purposes 4 seismic zones are defined. These are related to the Modified Mercalli Intensity Scale (MM) as follows,

Zone A	Seismic Zone of Destruction Risk, EM Intensity IX or more is probable.
Zone B	Seismic Zone of Heavy Damage Risk, EM Intensity VIII is probable.
Zone C	Seismic zone of Moderate Risk, EM Intensity VII is probable.
Zone D	Seismic Zone of little Risk, EM Intensity VI or less is probable

Table 3.2-2 Seismic Zones

For reasons of logic and economy, the extent of construction measures to improve earthquake resistance should be graded down from Zone A to C, while in Zone D no special measures are required. Other points of consideration will be the type of soil and foundations and the importance of the building. With regard to the grading of measures in order to improve earthquake resistance the following distinction *) can be made

Important: hospitals, dispensaries; telecommunication facilities, fire stations, water supply buildings, places of assembly such as cinemas, auditoriums, schools, museums, monuments, temples, etc

Ordinary: housing, hostels, inspection houses, offices etc *) the lists may vary depending on the local conditions.

Categories

The need for measures to meet adequate safety requirements can be expressed in categories, which are determined as a function of (1) the seismic zone, (2) the load bearing capacity of the soil and (3) the importance of the building, see Table 3.2-3


Construction category as a function of earthquake resistance requirements (highest requirements for category I)

Cat.	Combination of Conditions for the Category
I	Important Building on Soft Soil in Zone A
II	Important Building on Firm Soil in Zone A Important Building on Soft Soil in Zone B Ordinary Building on Soft Soil in Zone A
III	Important Building on Firm Soil in Zone B Important Building on Soft Soil in Zone C Ordinary Building on Firm Soil in Zone A Ordinary Building on Soft Soil in Zone B
IV	Important Building on Firm Soil in Zone C Ordinary Building on Firm Soil in Zone B Ordinary Building on Firm Soil in Zone C Ordinary Building on Soft Soil in Zone C

Notes:

- 1) Definition seismic zones and importance of buildings, see above
- 2) Firm soil refers to those having safe bearing value more than 10 t/m² and soft less than 10 t/m²
- 3) Weak soils liable to compaction and liquefaction under earthquake conditions are not covered here.

Table 3.2-3 Combination of categorial conditions

 earthquake effects, intensity scales, seismic zones, construction categories.

SESSION 4: DAMAGE: CATEGORIES AND CAUSES

Topic 4.1: Damage: Categories and Causes

From the structural behavior of buildings under horizontal inertia forces, it can be seen that different damage can occur, depending on the magnitude of the forces and the resistance in the critical parts of the structure.

Categories of Damage

The categories of damage of buildings are classified in Table 4.1-1 as a general guideline for repairs as suggested in the last column of the Table.

Factors Affecting Damage

The main factors controlling the damage on buildings are:

Structural Configuration Defects: The geometry of buildings in plan as well as elevation has a considerable effect in the distribution of seismic forces and influences the type and degree of damage. For example, unsymmetrical buildings (Figure 4.1-1) develop additional shear forces due to twisting and warping. Failure occurs at corners or openings (Figure 4.1-2) and weakly built corners of walls. Damage also occurs as a result of "hammering" between two adjacent dissimilar buildings. In general buildings with sudden change in mass and/or stiffness tend to develop unfavorable force distributions and concentration of stresses.

III Moderate Structural Damage	Large and deep cracks in walls; widespread cracking of walls, columns, piers; tilting or falling of chimneys; the load carrying capacity of structure is partially reduced	Building needs to be vacated, to be reoccupied after strengthening; structural restoration and seismic strengthening are necessary before architectural repairs
IV Severe Structural Damage	Very large and deep cracks; Gaps occur in walls, inner or outer walls collapse; approximately 50 percent of the main structural elements fail; the building takes a dangerous state	Building has to vacated; Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation
V Collapse	A large part of the building collapses	Clearing the site and reconstruction

Damage Category	Extent of Damage in General	Suggested Post Earthquake Actions
0 No damage	No damage	No action required
I Slight Non-structural Damage	Thin cracks in plaster, falling of plaster in limited parts	Building need not be vacated Only architectural repairs needed
II Slight Structural Damage	Small cracks in walls, falling of plaster over large areas; damage to non-structural parts like chimneys, projecting cornices etc; The load carrying capacity of the structure is not reduced appreciably	Building need not be vacated Architectural repairs required to achieve durability

Table 4.1-1 Categories of Damage [1]

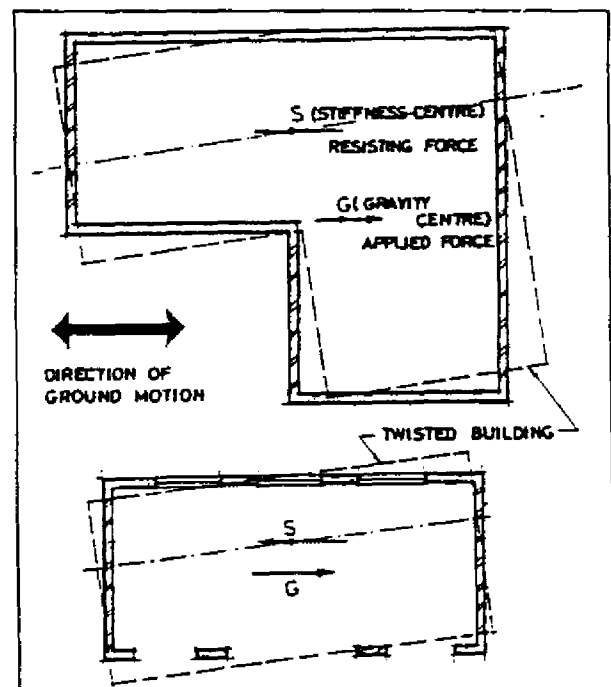


Figure 4.1-1 Torsion of Unsymmetrical Plans [1]

Foundations Soil Weakness. Buildings which are structurally strong enough to withstand earthquakes sometimes fail due to inadequate foundations. In many earthquakes, liquefaction of soil, landslides or settlement of soil have lead to catastrophic failure of buildings. Cracking and failure of superstructures may result from differential settlement of footings. Soft alluvium and loose sands with a high water table lead to conditions which cause failure due to settlement or liquefaction.

Certain types of foundations are more susceptible to damage than others. For example isolated footings of columns are likely to be subjected to differential settlement particularly where the supporting ground consists of different types of soils. Mixed type of foundations within the same building may also lead to failure due to differential settlement.

Very shallow foundations deteriorate because of weathering particularly when exposed to freezing and melting. Frequent flooding of foundations may also lead to deterioration. Shrinkage and swelling of soil also considerably affect shallow foundations, causing differential settlement and cracking even without earthquake.

Weaknesses in Walls and Frames. Unreinforced masonry walls are highly susceptible to damage because of their low tensile and shear resisting capacity. Further reduction in the strength of such walls and concentration of stresses occurs due to the door and window openings. Weak bonding mortar in masonry is a critical source of weakness.

Collapse of load bearing walls may also be due to failure of connections between walls, wall and roof and wall and foundation. Thus lack of structural integrity is the greatest source of weakness and may be responsible for severe damage or collapse.

The complete collapse or severe damage of frames may be caused by excessive column bending or failure of rigid joints of frame elements. Insufficient strength of structural elements and connections, and inadequate ductility may be responsible for damage.

Lack of interconnection in Roofs and Upper Floors Large

seismic forces develop at the levels of roof and upper floors because of heavy concentration of weight at this level or due to amplification of ground acceleration at higher levels. If the elements used in the roof or floors are not properly interconnected together and if the large seismic forces are not properly transferred to the supporting walls or frames through suitable connections between them, the roof and floors may be severely damaged or collapse completely.

The floor beams of the upper floor may jump out of the wall and cause the floor to fall onto a lower floor. This is so-called pancaking, where entire floors stack up on each other.

Poor Quality of Construction. In many instances the failure of buildings in earthquakes have been attributed to poor quality of construction like substandard materials, poor workmanship, inadequate skill in bonding, absence of "through stones" or bonding units, and improper and inadequate connections.



Earthquake damage-categories, earthquake damage-causes.

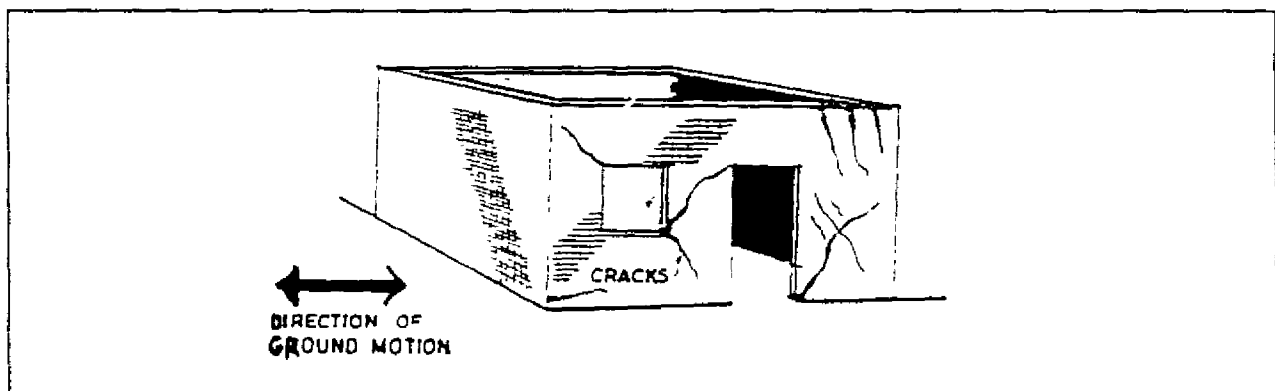


Figure 4.1-2 Cracking in Shear Wall at Corners of Opening

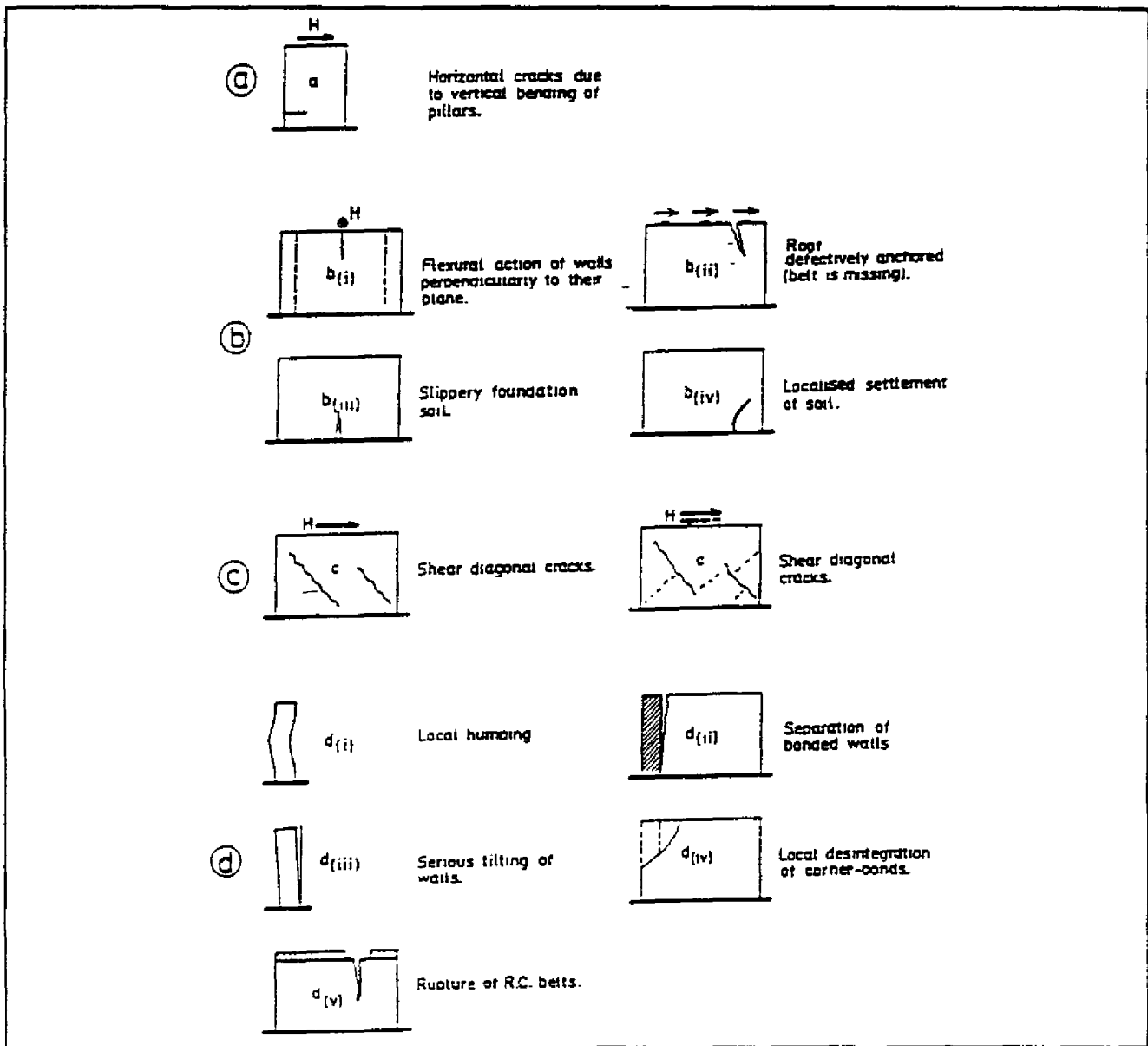


Figure 4.1-3 Classification of Masonry Damages

SESSION 5: FAILURE OF BUILDINGS

Topic 5.1: Failure of Buildings

During an intense earthquake the roof of buildings tend to separate from supports, the bearing walls tend to tear apart and the infill walls fall out of the frame. It is essential that the various parts and elements of the building be tied together. The mechanisms of failure are analyzed below.

Free Standing Wall

Consider the structural elements shown in Figure 5-1-1. In (a) the wall A is free standing and the ground motion is acting transverse to it. The force acting on the mass of the wall tends to overturn it. The resistance of the wall is by virtue of its weight and the tensile strength of its mortar, it

is obviously very small. This wall will collapse by overturning.

The free standing wall B in Figure 5-1-1 (b) is subjected to ground motion in its own plane. It is clear that in this case, because of its large depth in the plane of bending, the wall will offer much greater resistance. Such a wall is termed a shear wall.

An unreinforced masonry wall acting as a shear wall will generally develop a horizontal crack due to bending tension and then slide due to shear.

A bounded wall (one carrying reinforcing steel or a strong

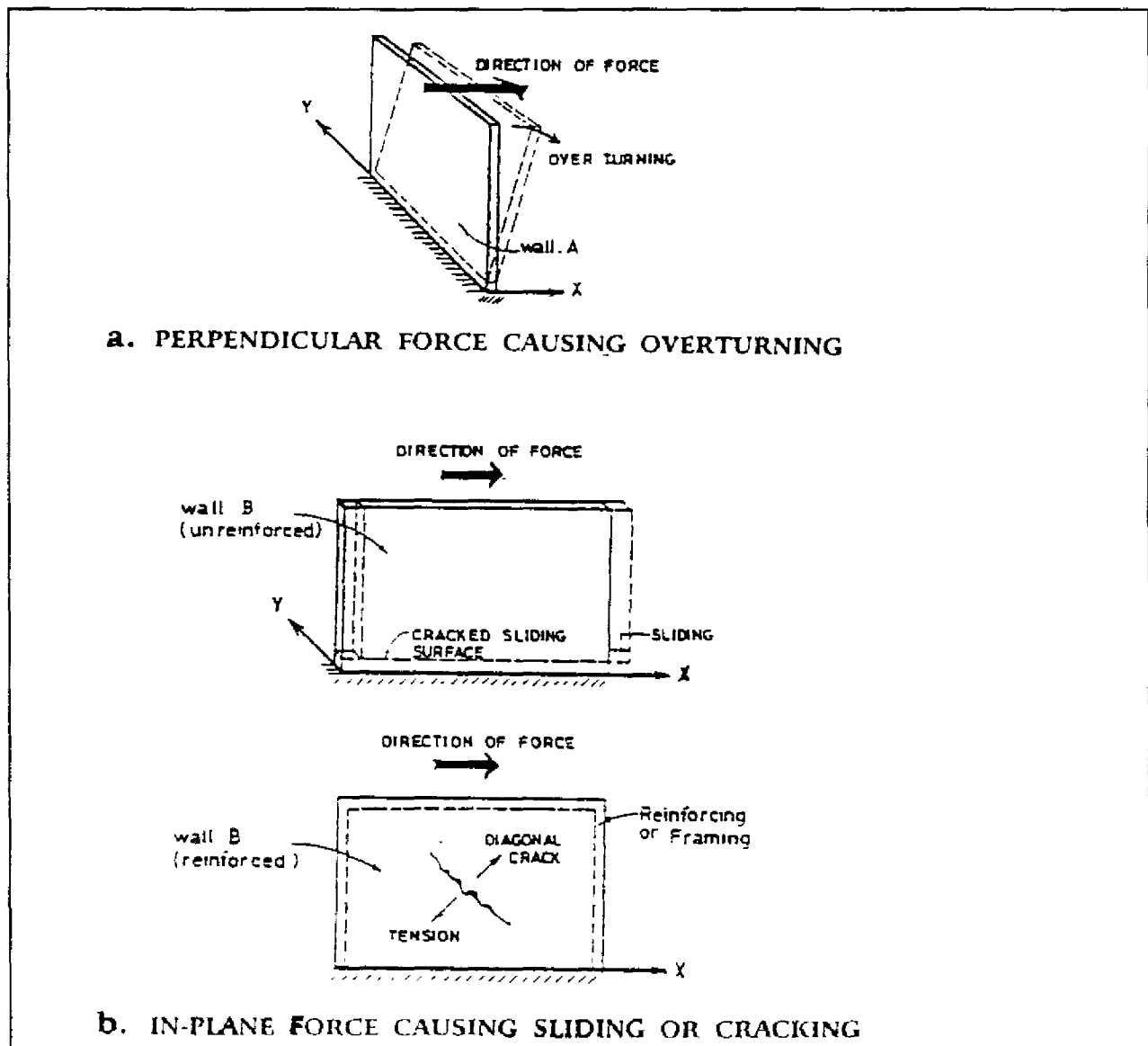


Figure 5.1-1 Free standing Wall

frame on its periphery), on the other hand, may develop diagonal tension cracks due to shearing. Diagonal tension cracks due to shearing will also be developed in long low walls. In ground motions parallel to y-axis, wall A will act as shear wall and wall B will topple over.

Wall Enclosure without Roof

Now consider the combination of walls A and B as an enclosure shown in Figure 5.1-2. For the x-direction of force as shown, walls B act as shear walls offering resistance against the collapse of walls A. As a result wall A now acts as vertical

slabs supported on two vertical sides and the bottom plinth and subjected to the inertial force of their own mass. Near the vertical edges, the wall will carry horizontal bending moments for which the masonry has little resistance. Consequently cracking and separation of the walls may occur along lines shown in the Figure. As far as vertical bending is concerned, the wall gets a precompression from its own weight and can absorb some bending tensions. The situation will become the same for walls B for ground motion along the x-axis.

If the connection between walls A and B is not lost, the building will tend to act as a box and its resistance to horizontal loads will be much larger than that of walls B acting separately. Most unreinforced masonry enclosures, however, have very weak vertical joints between walls meeting at right angles. This is because the construction involving toothed joints is often not properly filled with mortar. Consequently the corners fail and lead to collapse of walls. The longer the walls are in plan the less will be the support provided to them from the cross walls and the supportive box effect will also be lower.

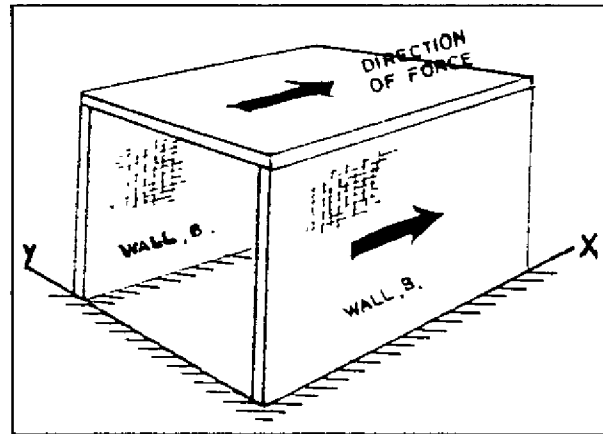


Figure 5.1-3 Roof on Two Walls [1]

Roof on Two Walls

In Figure 5.1-3 a roof slab is shown to be resting on two parallel walls B, while the earthquake force is acting along the x-axis. With enough adhesion between the slab and the walls, the slab will transfer its inertia force at the top of walls B, possibly leading to shearing and overturning. To be able to transfer its inertia force to the two end walls, the slab must have enough strength in bending in the horizontal plane.

Whereas reinforced concrete or reinforced brick slabs will possess such strength inherently, other types of roofs or floors such as timber or R.C. joists with brick tile covering will be very flexible. The joists will have to be connected together and fixed to the walls so that they are able to transfer their inertia force to the walls. After this load transfer, the walls B must have enough strength as shear walls to withstand the

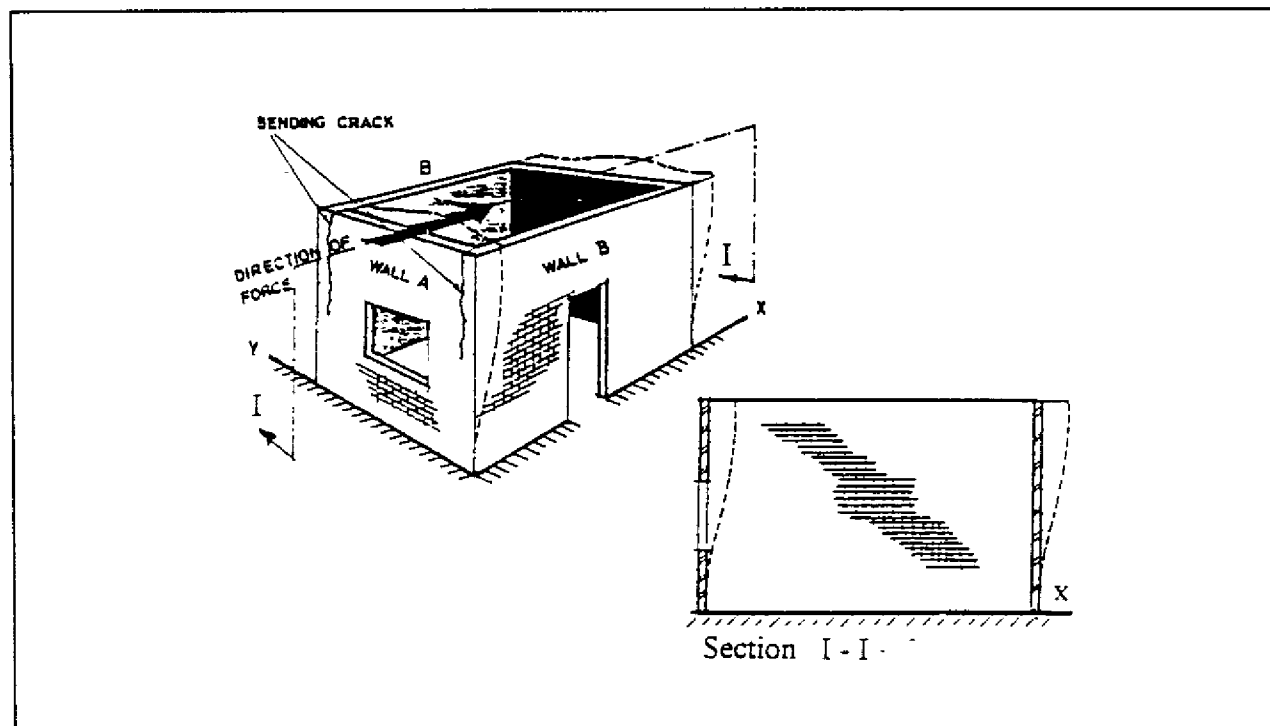


Figure 5.1-2 Wall Enclosure without Roof [1]

force from the roof and its own inertia force.

It is quite clear that when subjected to ground motion along the y-axis, the structure shown in Figure 5.1-3 will collapse easily because walls B have very little bending resistance in the y-direction. In long buildings, the end walls will be too far to offer much support to the long walls, with similar effects.

Roof on Wall Enclosure

Let us now consider a complete wall enclosure with a roof subject to earthquake force acting along x-axis as in Figure 5.1-4. If the roof is rigid to act as a horizontal diaphragm, its inertia will be distributed to the four walls in the proportion of their stiffness. Since the shear walls B are several times stiffer than the walls A in the x-direction, the roof inertia will almost completely be transmitted to walls B. In fact the plate-action of walls A will be restrained by the roof at the top and horizontal bending of the walls A will be reduced. On the other hand if the roof is flexible, the roof inertia will go to the wall on which it is supported and the support provided to plate action of walls A will also be little or zero. Again, the enclosure will act as a box to resist the lateral loads, but this action decreases in value as the plan dimensions of the enclosure increase.

Roofs and Floors

The more common types of roofs and floors used in buildings are the following:

1. Slabs or slab and beams (reinforced concrete slab or reinforced concrete slab with bricks).
2. Joists (timber, reinforced concrete, prestressed concrete,

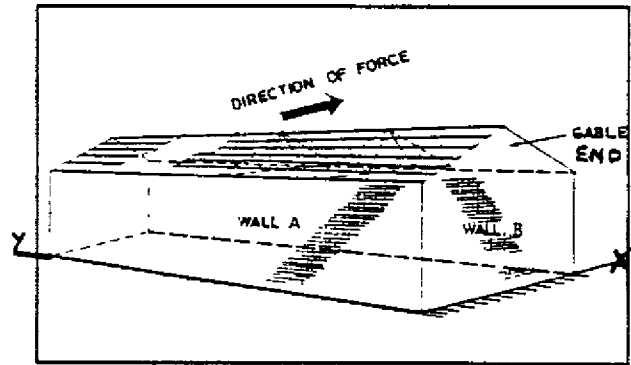


Figure 5.1-5 Long Building with Roof Trusses [1]

- precast slab units, stone slabs)
- 3 Jack arches or flat arches resting on steel joists
- 4 Roof trusses

One must understand their individual performance under stress. Those which are rigid and flat and are tied to the masonry, have a binding effect on the walls.

The examples are slabs or slab and beam construction directly cast over the walls or jack arch floors or roofs provided with horizontal ties and laid over the masonry walls with good mortar. Others which simply rest on the masonry walls will offer resistance to relative motion through friction only which may not be reliable.

To illustrate the point, let us consider the case of a floor consisting of timber joists placed at a spacing of 20 to 25 cm with brick tiles placed directly over the joists and covered with clayey earth. Now the brick tiles have no binding with

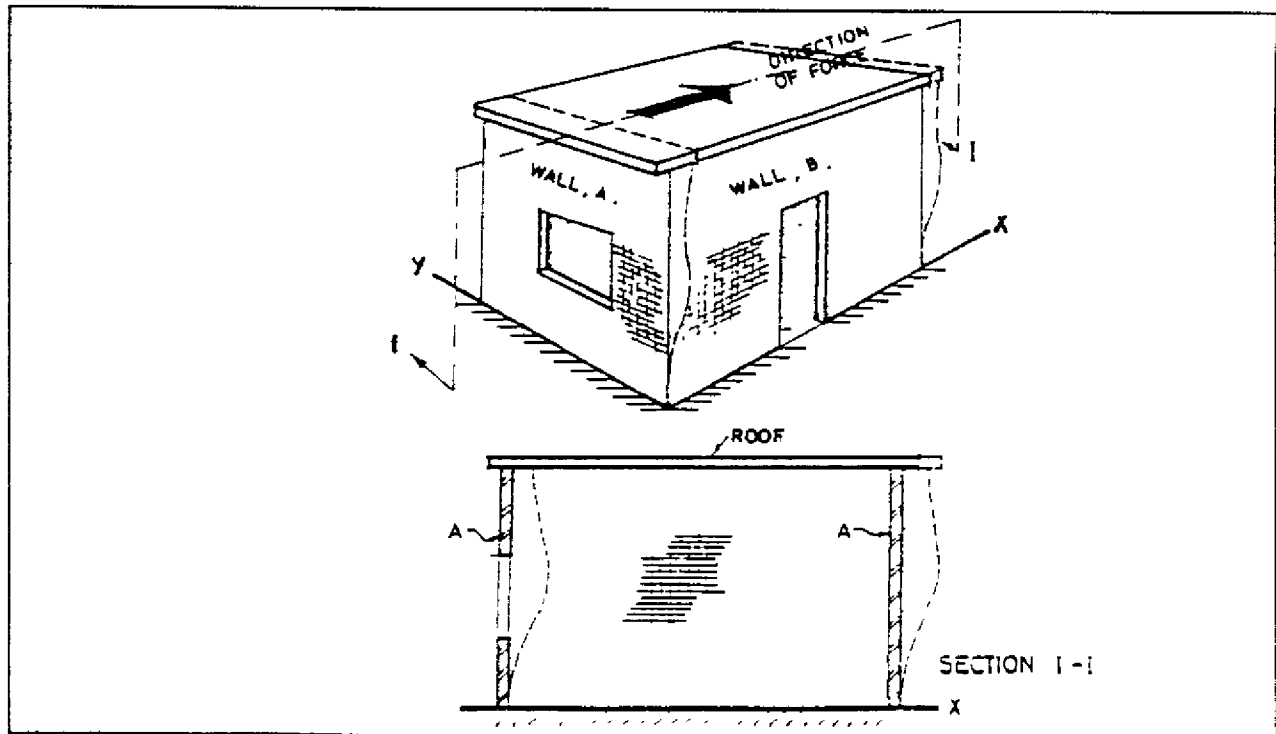


Figure 5.1-4 Roof on Wall Enclosure [1]