1. 0 INTRODUCTION

Uganda has experienced a series of earthquakes of varying magnitude during the past century; the major ones being three which occurred on 18th. May, 1945 of magnitude 6.0 that left 5 deaths, 8 injuries, and some houses destroyed; the second one struck on 20th. March 1966 leaving 157 deaths, 1323 injuries and 6752 huts and houses damaged or destroyed; the damage was estimated at £1 million. The most recent one occured on 5th.February 1994 which left 8 deaths, 2693 buildings demaged or destroyed; damage was estimated at $60 millions.

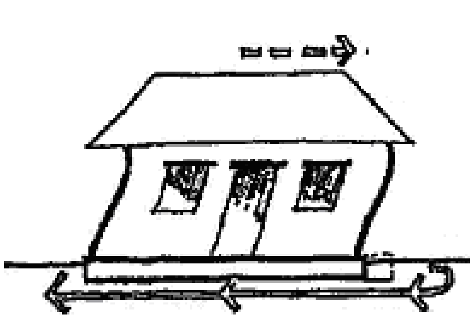
After the 1994 earthquake, Government commissioned a team of consultants to assess the damage and recommend measures to mitigate effects of future earthquake disaster. These consultants recommended among others the need to develop guidelines for construction of earthquake resistant buildings in earthquake prone areas. Accordingly, a National Task Force (NTF) was set up to execute this task. The NTF conducted investigations and concluded that in order to reduce or avoid structural damage and increase safety of the population in earthquake prone areas, special attention should be given to: selection and preparation of the site and building position; selection of building materials and design of the building, use of special techniques for reinforcing foundations, floors, walls and roofs, quality of workmanship, maintenance of buildings and addressing non-structural hazards.

The findings from the investigations provided an essential input into the preparation of guidelines for earthquake resistant building construction. This Handbook is structured to give an overview about earthquakes, mitigation of structural and non-structural hazards, and earthquake disaster preparedness. There has been an attempt for the first time in Uganda to incorporate earthquake considerations in the Seismic Code of Practice for Structural Designs, which is expected to be adopted as part of the Building Code.

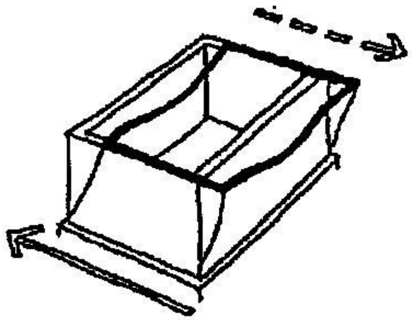
There is however little attention that has been paid to address the non-structural aspects that are equally important in inflicting injury and damage to lives and property during earthquake tremors. This Handbook has therefore been prepared to guide the construction of earthquake resistant buildings and enhance seismic safety against both structural and non-structural hazards.

1. 1 FACTS ABOUT EARTHQUAKES

An earthquake is the motion or trembling of the ground due to sudden displacement of rock in the earth's crust. It may be caused by the movement of large continental plates, which collide, move apart or rub against each other, building up immense tension within the rock formations, which at a certain point readjust themselves with a sudden motion, sending out the accumulated energy in form of seismic waves in all directions. Other causes include: volcanic eruptions and construction of dams to mention but a few.

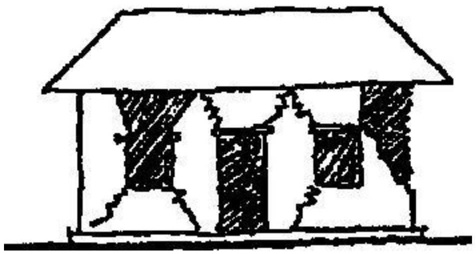


Horizontal movements



Torsional (twisting) movements

Seismic waves comprise horizontal, vertical and torsional (twisting) movements acting simultaneously. Weak, non-elastic components break apart or disintegrate; elastic materials vibrate and absorb energy released by the tremors; while tough and rigid materials can remain unaffected. Destruction of buildings mainly begins with walls falling apart; the ceilings and roofs, lacking support, follow suit, burying the dwellers and property beneath them.



The resulting tension causes cracks in areas of weakness in the walls.

Some walls collapse as a result.

A series of smaller earthquakes follow a major earthquake and can lead to further collapse of buildings, greatly complicating rescue work. Other effects of earthquakes include: ground failures (landslides, liquefaction, lateral spreads, differential settlements & ground cracks), surface faulting (horizontal or vertical movement of the earth's surface), tectonic uplift, subsidence and tsunamis (huge waves in the ocean / sea resulting from earth tremors.

Weak joints especially in corners lead to cracks

The building may subsequently collapse like the above classroom block in Bundibugyo.

1.2 Categories of Damage	Extent of damage	Suggested post earthquake actions
Slight non-structural damage	Thin cracks in plaster, falling of plaster in limited areas	Building should not be vacated. Only masonry repairs are needed.
Slight structural damage	Small cracks in walls, falling of plaster in large areas, damage to non-structural parts like chimneys. The load carrying capacity is not reduced appreciably.	Building should not be vacated. masonry repairs needed to achieve durability.

Categories of Damage	Extent of damage	Suggested post earthquake actions
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 should be vacated, to be re-occupied after strengthening. Structural restoration and seismic strengthening are necessary before masonry repairs.
Severe structural damage	Very large and deep cracks. Gaps occur in walls; inner and outer walls collapse; approximately 50% of the main structural elements fail. The building takes a dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before re-occupation.
Collapse	A large part of the building or the entire building collapses.	Clear the site, carefully remove damaged building elements and carry out reconstruction work.

1.3 Seismic Source Zones

Earthquakes in Rwenzori Region are associated with movements along rift valley faults but it is not possible to associate an individual earthquake with the causative fault. The following assumptions were used in the zoning of the area:

- each source has reasonably uniform Seismicity. Poisson model assumes that each point within a source zone has the same probability of being the epicentre of a future earthquake, and
- the zoning is consistent with the regional geology and tectonics.

Based on the available seismological and geological information the study region is modeled by four seismic source zones shown in Figure 3.a. The zones, numbered from 1 to 4, have been defined as polygons to satisfy the input requirements to the hazard computer program. Superimposed on the zone map are earthquakes of $m \geq 4.5$, after removing aftershocks, used in the delineation of the source zones. In order to include earthquakes that may have some influence on the seismic hazard of Rwenzori Region the zones go beyond the region by at least two degrees.

Zone 1 consists of Albert, George and Semliki basins and Rwenzori mountain block. A node between NNE-SSW trending Lake Albert basin, N-S trending Nile rift and the E-W trending river Nile defines the northern boundary. A line connecting Bunyaruguru and Kikorongo-Katwe volcanic fields marks southern boundary. Western and eastern boundaries are marked by rift valley border faults.

Zone 2 contains Edward basin. Its southern boundary is marked by Virunga volcanic field, which is aligned along a fracture zone transverse to the rift axis. The western and eastern boundaries are marked by rift valley border faults. The northern boundary is the same as the southern boundary of zone 1.

Zone 3 is part of rift valley but with less seismic activity than zones 1 and 2. Zone 4 is characterised by splay faults. The predicted ground motion in the figure 3.b. below depends on three crucial variables:

- the relation used to predict ground acceleration expected at a given distance;
- assumed maximum magnitude on Richter scale (m_u) and
- recurrence interval of largest earthquakes (activity rates).

Seismic waves travel at different speeds in different types of rock. Passing from rock to soil, the waves slow down but get bigger. A soft, loose soil will shake more intensely than hard rock at the same distance from the same earthquake (that is certain soils greatly amplify the shaking in an earthquake). The looser and thicker the soil is, the greater the amplification will be. It has not been possible to include site condition (site effects) parameter in the determination of PGA since soils (soil type, thickness, and their seismic velocity) in the region are not properly mapped. In addition, there are no accelerograms recorded in the study area. Thus amplification factors for different sites are not also determined. Consequently the estimated PGA values in Figure 3.b. apply only to firm-rock sites.

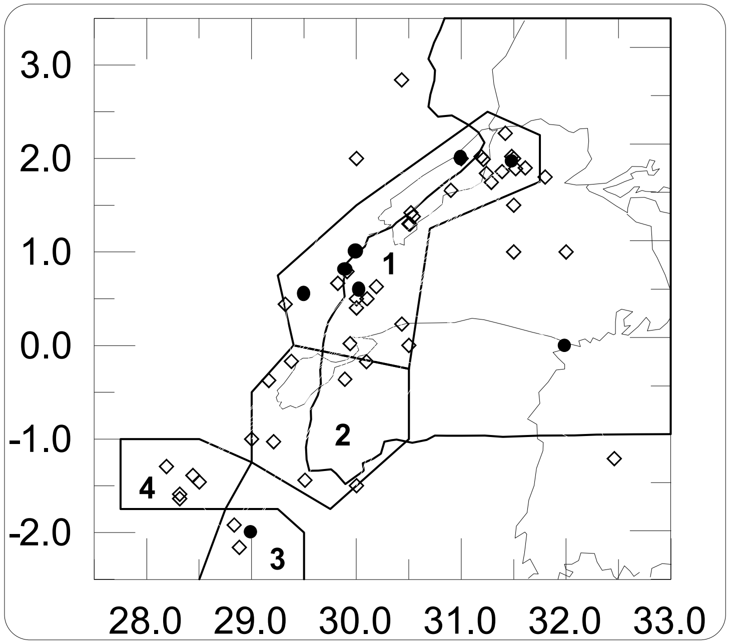


Figure 3.a Map Showing Seismic Source Zones and Seismicity of Western Uganda

Symbols :

- Open diamond : Magnitude = 4.5-5.9,
- Solid circle : Magnitude ≥ 6.0

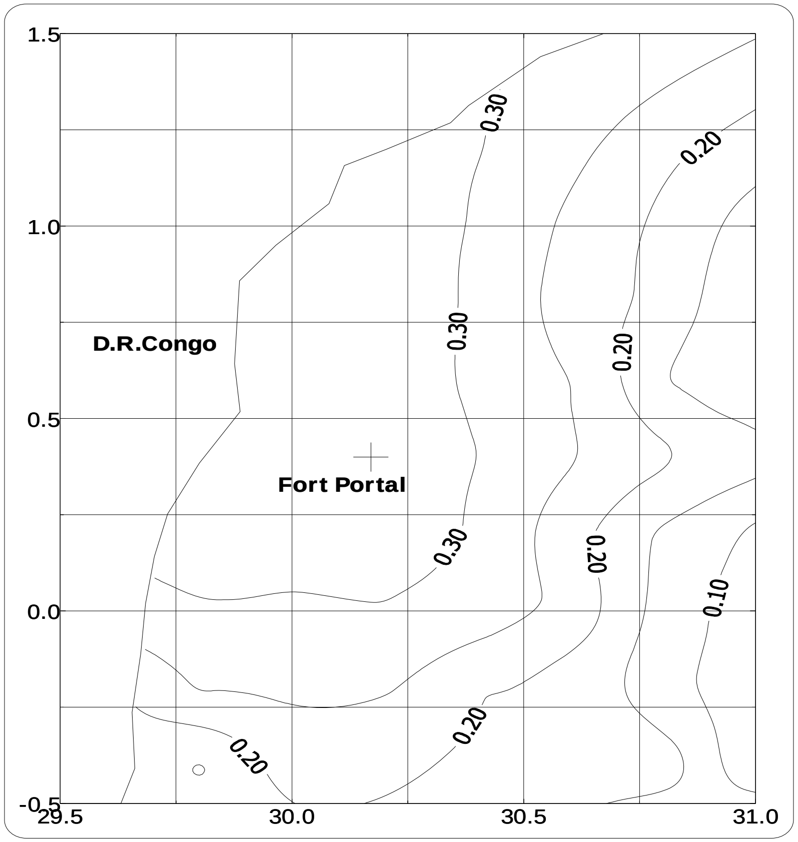


Figure 3.b. Probabilistic seismic map for peak horizontal acceleration on firm-rock site conditions and 10% probability of being exceeded in 50 years. Contours indicate peak acceleration in %g units.

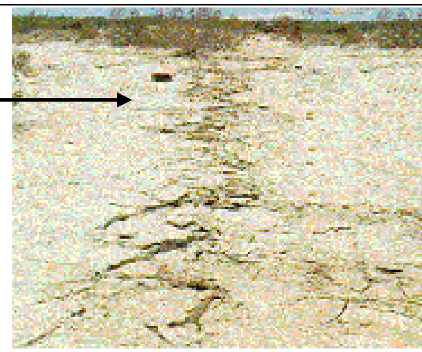
2. EARTHQUAKE DISASTER MITIGATION - STRUCTURAL ASPECTS

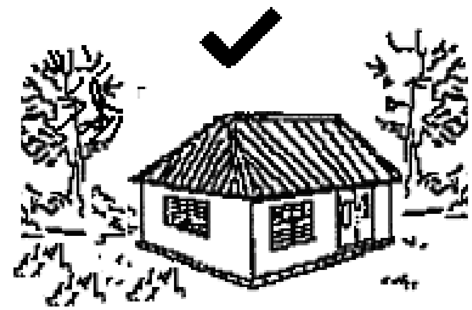
In order to reduce the danger of structural damage and to increase the safety of a building & its occupants, serious attention should be paid to ensure that the following aspects are adequately addressed:

- The selection and preparation of the site and the building position;
- The selection of building materials and design of the structure;
- The use of special techniques for reinforcing foundations, floors, walls, & roofs; and
- The quality of workmanship and frequency of maintenance of structures.

2.1 Site Selection & Preparation

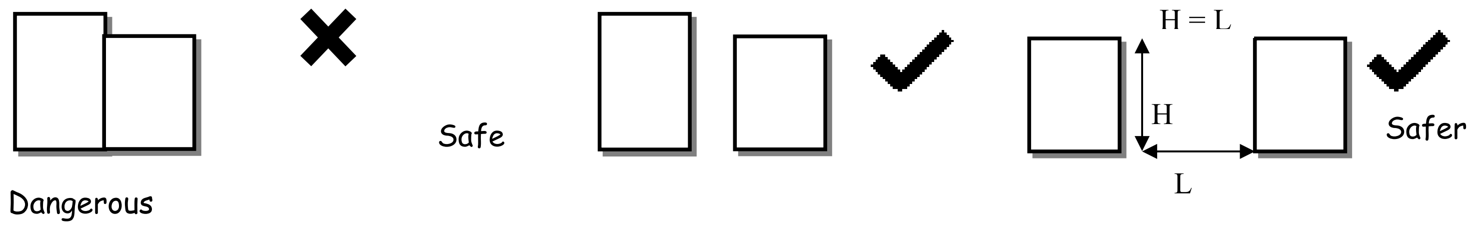
- The construction site should be as far as possible from the **fault-line**
- Avoid sites found in filled ditches and water courses;
- Avoid sites located in a waterlogged area



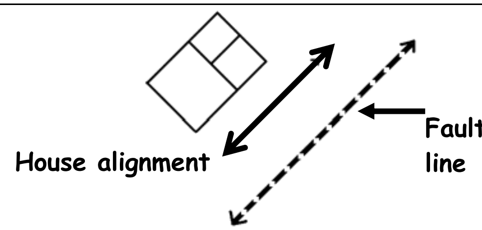


Flat terrain is the best.

- Provide sufficient distance from the neighbouring structures:
- The minimum distance between 1-storey structures should be equal to their height.
- If a new building must be built less than the minimum distance, any separation is better than none.
- Never interconnect the walls of two buildings.



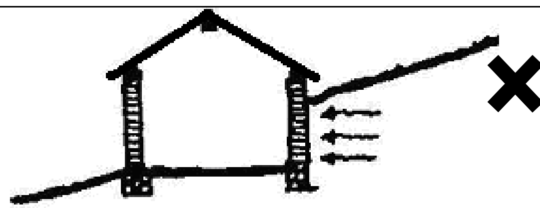
- Align the building so that its length is parallel to the nearest fault line. This will help the structure go "with" and not "against" the earthquake waves.



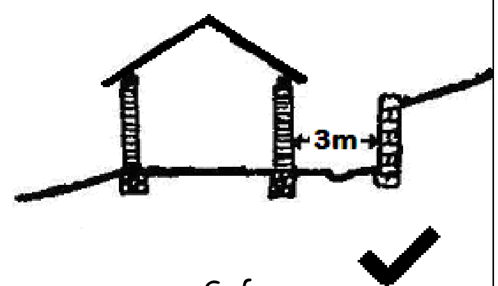
House aligned with fault line

2.2 Construction along a slope

- The house should not be cut into the slope as adjacent walls might collapse due to the horizontal forces of the earth.
- Allow a minimum distance of 3 m from the adjacent wall as shown in the illustration.

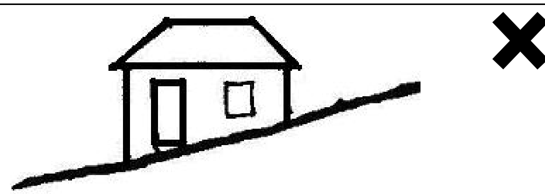


Dangerous



Safe

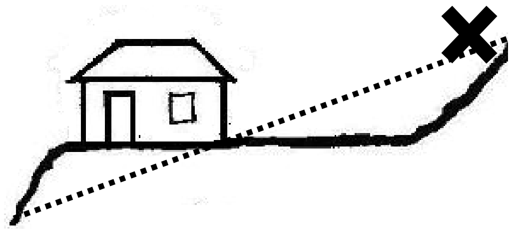
- Avoid stepped foundations along slopes, which result into unequal heights of the walls. Level the site and build level foundation with equal wall height.



Dangerous

Dangerous

- The building should not be erected on the fill section of the slope as it might easily slip down or even very close to the steep slope as it might be destroyed by falling rocks or landslide



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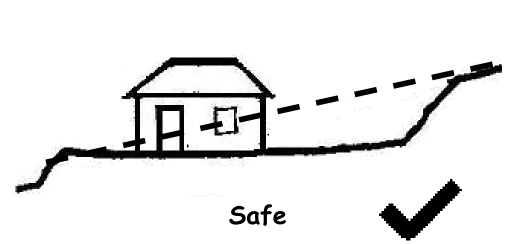


- It is recommended that massive heavy buildings be built on rocky soils and/or piles, whereas light flexible structures can stand on softy sandy soils.

- Multi-storeyed structures should be avoided in earthquake prone areas. If they have to be built then seek professional advice of registered Structural Engineers.

Build on rocky ground with appropriate reinforcement or avoid completely

Heavy Structure on firm ground

Light Structure on soft ground

2.3 Design for Responsiveness to Seismic Forces

According to the findings based on the baseline surveys of the Task Force, the horizontal Peak Ground Acceleration (PGA) values applicable to the firm-rock site conditions at 10% probability of a 50 year exceedance for Rwenzori Region varies from 0.1 g to 0.34g. The engineering design coefficients for the net translational force as a function of the height and floor area of the building are derived from the above PGA values for the firm-rock ground site conditions in the region.

In deriving the net translational force for lifeline buildings (hospitals, schools, places of worship, public offices, police stations, and public halls) the PGA value applied is 0.3g while for other buildings a PGA value of 0.2g has been adopted. The value of net translational force is a product of mass and PGA (kg m s^{-2}). Practically the net translational force operates on the impacted surface of the building in a manner similar to the wind forces. The table below presents some net translational force values applicable to a single and double storey building.

Summary of the Net Translational Force Values for buildings in Rwenzori Earthquake zone.

(Kilo Newtons- Kn)

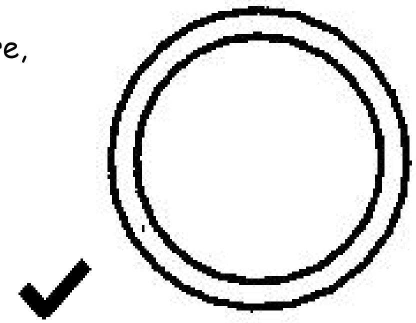
Category	**Institutional**				**Others**				**Remarks**
Floor Area (M^2)	**20**	**50**	**100**	**200**	**20**	**50**	**100**	**200**	The larger the surface area, the bigger is the net translational force.
Single Storey	0.44	1.47	5.69	11.77	0.29	0.981	39.24	78.48	
Double Storey:									
Ground Floor		58.85	118	118		39.24	78.5	78.5	Greater force is exerted on first floor where the centre of gravity is.
First Floor		117.72	235	235		78.48	157	157	
Second Floor		58.86	118	118		39.24	78.5	78.5	

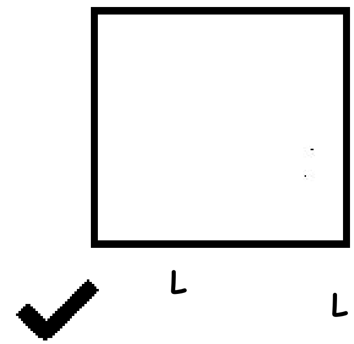
2.3.1 Shapes

The shape of the plan of the house influences its stability to a great extent; the following basic considerations must be borne in mind:

- The more compact a plan, the better the stability.
- The Building and its super structure should be simple, symmetric and regular in plan and elevation to prevent significant torsional forces,
- Avoid large height : width ratio and large plan area.

- The circle is better than a square, which is also better than a rectangular shape.





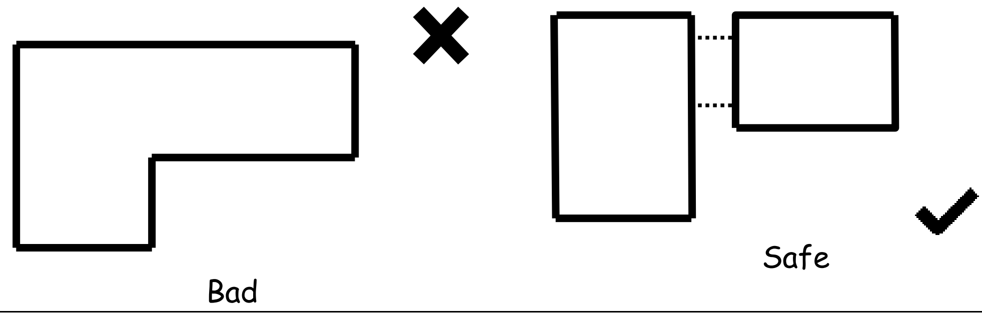
- The Rectangle is less stable and is badly affected by torsional forces which lead to collapse of the walls.

Improve with appropriate reinforcements;

The length L should not exceed 3W.

$L \leq 3W$

- L – Shaped plans are less stable
- The best solution therefore is to separate the elements as shown.

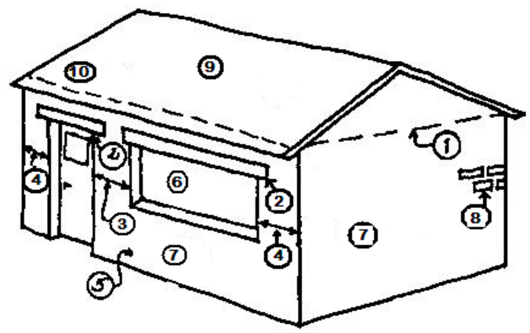


2.3.2. General Structural Design Principles for Earthquake Resistant Structure

- The foundation, walls and roof are well interconnected and so rigid that no deformation occurs during the earthquake
- Walls are flexible enough allowing the deformation to absorb kinetic energy of the earthquake. Use ring beam to take bending forces and the joints between wall & ring beam and ring beam and roof must be strong enough.
- Fix the roof to the columns that are separated from the wall, so that both structural systems can move independently since they have different frequencies.

2.3.3 Common Structural Design Mistakes

1. Ring beam is lacking
2. Lintels over openings do not reach deeply enough into masonry
3. Distance between door and window is too small
4. Distance between openings and wall corner is too small
5. Plinth or foundation wall is lacking
6. The window is too wide in proportion to its height

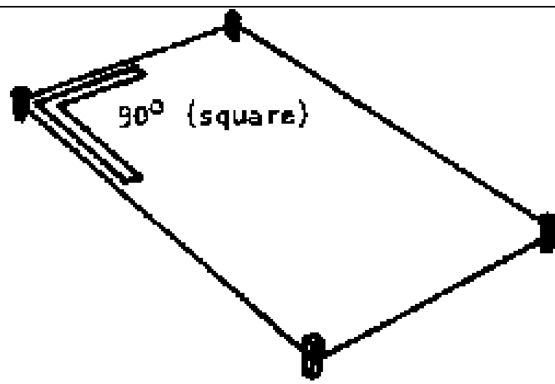


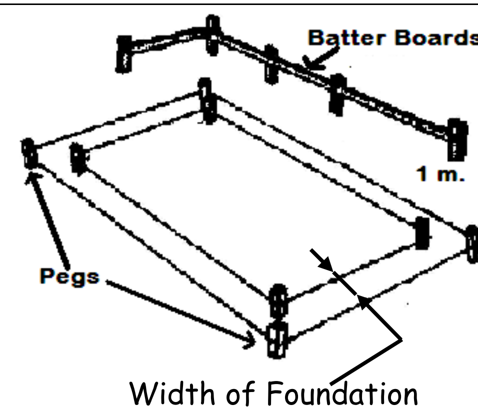
7. The wall is too thin in relation to its height
8. The quality of the mortar is too poor, the vertical joints are not totally filled, and the horizontal joints are too thick (> 15 mm)
9. The roof is too heavy
10. The roof is not sufficiently fixed to the wall.
11. Ground beam is lacking

2.4 Setting Out

Before setting out a building, the site has to be prepared and leveled. The following tools are required during the setting out:

- Pegs & profile/batter boards
- Hammer
- Building Line/String/Cord
- Tape Measure
- Mason's Square
- Wire nails & survey equipment if available





2.5 Building Foundation

The stability of a building depends primarily on the foundation it is built on. The construction of the foundation is in turn dependent on the type of building and, above all, on the load-bearing capacity of the ground.

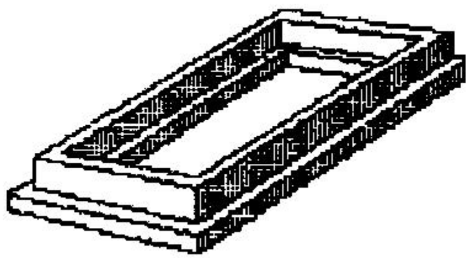
The foundations are used to:

- Securely anchor the house to the ground to prevent forces e.g. wind or earthquake from lifting the entire building or blowing it over or pulling it down;
- Transmit the building loads to the ground to ensure stability of the structure; and
- To provide a solid level base for the foundation walls.

2.5.1.Types of Foundations

Linear or Strip Foundation:

This is the most common type of foundation, consisting of a continuous strip, which supports a load-bearing wall along its full length.

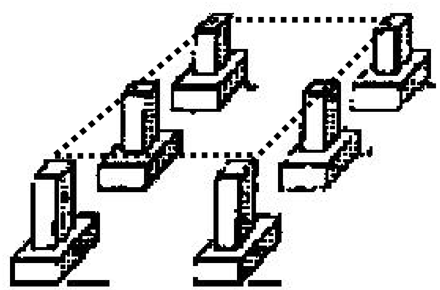


Linear or Strip Foundation

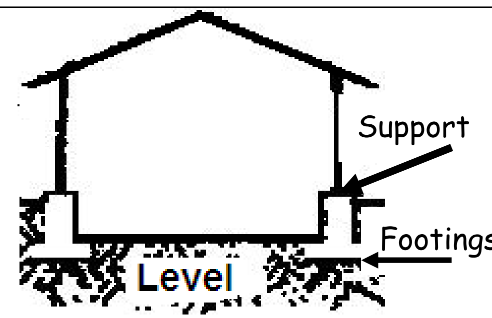
It is also used to bridge or cantilever over soft portions of the ground, in which case, it must be reinforced.

Spot or Pad Foundation:

This is the common foundation for columns or poles, and comprises a square/ rectangular/circular footing, which is thicker than the width or diameter of the column or pole, the length and breadth each being at least three times the thickness.

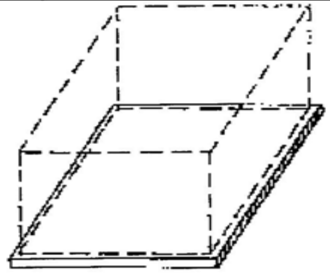


Spot or Pad Foundation



Slab or Raft Foundation:

This type of foundation is often used for small buildings or structures with uniformly distributed loads (eg water tanks). However, it can also be used for large structures as well.

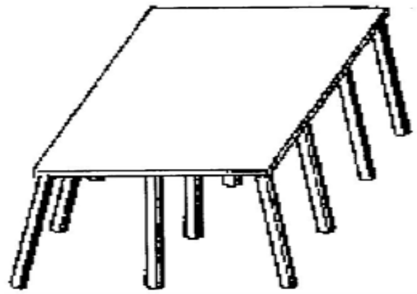


Slab or Raft Foundation

Slabs on homogeneous ground can do without reinforcement, but over large areas, reinforcement is advisable, as non-uniform ground conditions lead to differential stresses.

Pile Foundation:

Building on poor soils or under water calls for this type of foundation. Holes are dug down through the weak soil up to the loadbearing layer, and filled with stable foundation material (either placed in situ or precast).

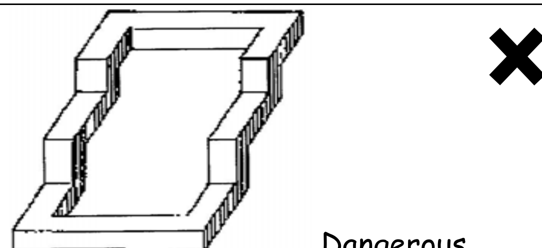


Pile Foundation

The piles carry a reinforced concrete slab or are connected at the top by beams, which act like strip foundations. Lateral stability is achieved by placing some of the piles at a slant (raked piles).

Stepped Foundation:

Building on sloping ground makes a stepped foundation necessary. It is a special form of strip foundation, designed to save material, and to provide horizontal surfaces at intervals along the slope.



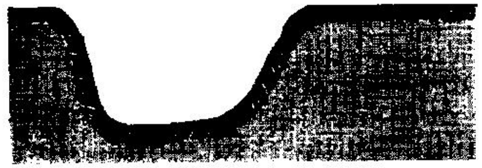
Dangerous

Stepped foundation

In earthquake prone areas, stepped foundations are less stable hence should be avoided, unless improved by reinforcement.

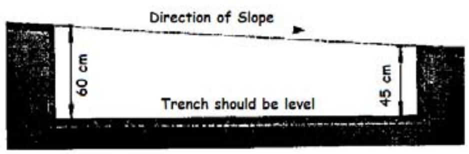
2.5.2 Excavating a Foundation

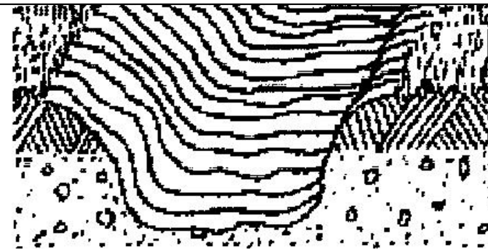
Foundation trenches should be carefully dug to provide a hard, level bottom surface and side walls at right angles to it. Rounded edges must be avoided.



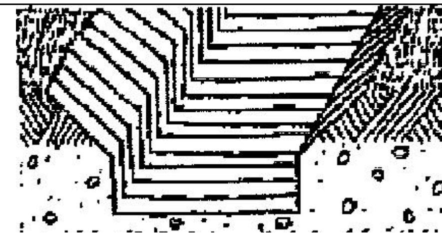
Incorrect Trench – Not Square

Trench : Correct – Square



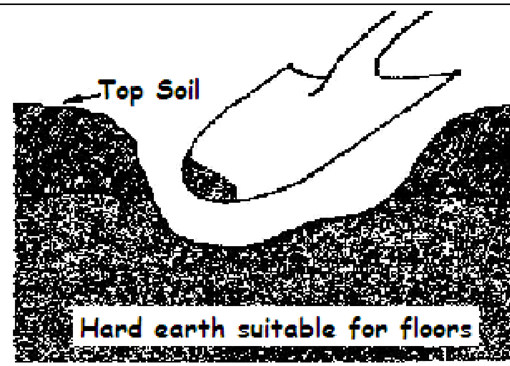


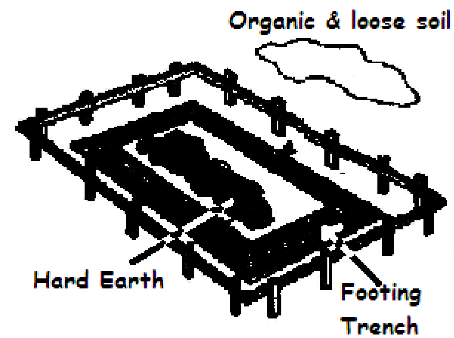
Wrong



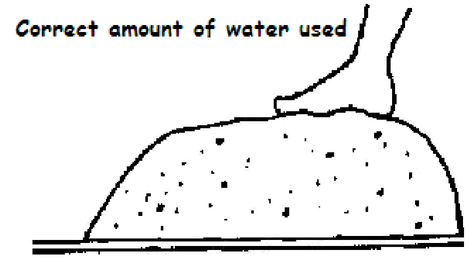
Right

Some of the excavated murram soil should be retained for backfilling, when the foundation wall is ready. The backfill should have the same characteristics (soil type, moisture, density) as the surrounding, undisturbed soil. Don't use black cotton (topsoil) for backfilling.





Reinforced concrete foundation should be provided where the ground is not firm. Make sure that the impurities in the sand are removed by washing and sieving or screening. Use appropriate sizes of aggregates and right ratios.



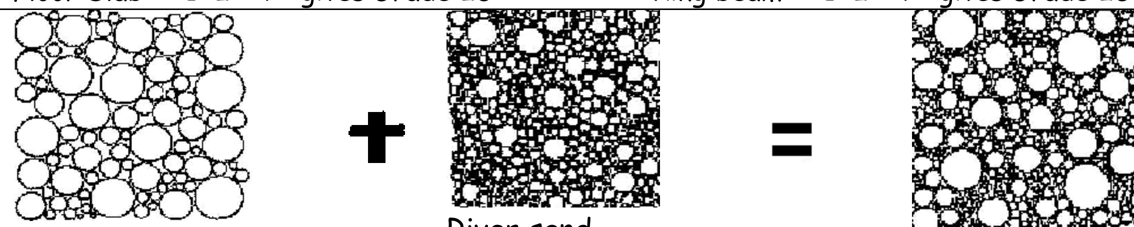
Example of recommended ratios for: Cement : Sand : Aggregate

Foundation: 1: 3: 6 – gives Grade 20
Columns 1: 1.5 : 3 – gives Grade 25
Floor Slab : 1: 2 : 4 – gives Grade 25

Ground beam: 1: 1.5: 3 – gives Grade 25
Ring beam 1: 2 : 4 – gives Grade 25

It may be necessary to blend types of sand in order to get the best mix.

Cement : Sand Ratio for bonding and plaster work : - 1: 4

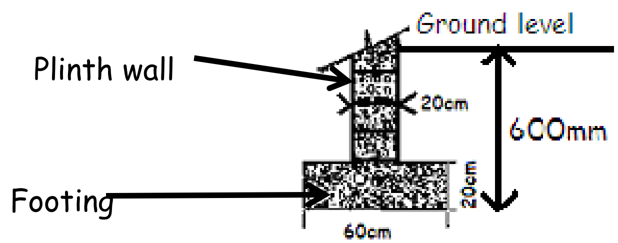


Lake sand

River sand

2.6 The Plinth Wall

The thickness of the plinth wall should be at least one third of the length of the footing. The plinth wall should preferably be thicker than the wall it supports and high enough above ground to protect the wall from rain splash.



The plinth should be at least 600 mm below ground level.