FOREWORD

On 8th October, 2005 the worst earthquake in the history of Pakistan, measuring 7.6 on the Richter scale, struck Kashmir and the northern areas of Pakistan. According to an official count, 80000 people lost their lives, thousands were injured and millions were left homeless.

It is a known fact that it is not earthquake that kills people; it is the destruction of the buildings which cause human and financial loss. Therefore, if the buildings are constructed in such a way that they can withstand the earthquake forces, the life and material loss can be minimized significantly. Keeping in view this fact, in the wake of 8th October 2005 earthquake, several governmental and non governmental organizations launched projects that were aimed at the reduction of disastrous effects of the earthquakes in future. UNDP, a subsidiary of United Nations Organization, also started few such projects, one of which included the development of an easy and understandable pictorial manual, following which the residential buildings can be made safer against earthquakes. On the basis of his vast experience and technical expertise, this project was handed over to Dr. Qaisar Ali, a distinguished professor of civil engineering department, NWFP, University of Engineering & Technology, Peshawar.

This manual tries to provide instructions regarding materials and pictorial presentations for the construction of earthquake resistant construction of buildings. This manual is focused on construction in those areas of Pakistan which are prone to high intensity earthquakes e.g., Quetta, Mansehra and Chitral etc. However, these guidelines are also applicable to earthquake resistant building construction in the rest of Pakistan, with some amendments, which are given at the end of the manual. Moreover these guidelines are applicable to one or two storey buildings only.

People are generally of the view that earthquake resistant construction increases the cost of construction manifold. This is a wrong notion. We can confidently state that by following the instructions in this manual, earthquake resistant houses can be constructed in any part of Pakistan with only 5 to 10% addition to the cost.

At the end we expect that this manual will be equally beneficial for laymen, masons, contractors and site engineers dealing with building construction. INSHALLAH

Seismic Hazard Zones

Based on the intensity of earthquakes, a given region or a country can be divided into different seismic zones. Pakistan is also divided into such four zones. Zone 1 refers to an area which experiences earthquakes of light intensity. Zone 2 includes the areas where earthquakes of moderate intensity can be expected. Similarly, severe earthquakes may occur in the zone categorized as zone 3. Zone 4 is the zone which is struck by earthquakes of very high intensity.

Seismic zoning of major cities of Pakistan is given in Table 1. In addition; the seismic zoning map of Pakistan is given in Figure 1, in which seismic zones of all the cities of Pakistan are shown.

Table 1: Seismic Zones of different cities of Pakistan

City	Zone	City	Zone
Islamabad	2B	Karachi	2B
Lahore	2A	Hyderabad	2A
Faisalabad	2A	Quetta	4
Peshawar	2B	Ziarat	4
Abbotabad	3	Gilgitt	3

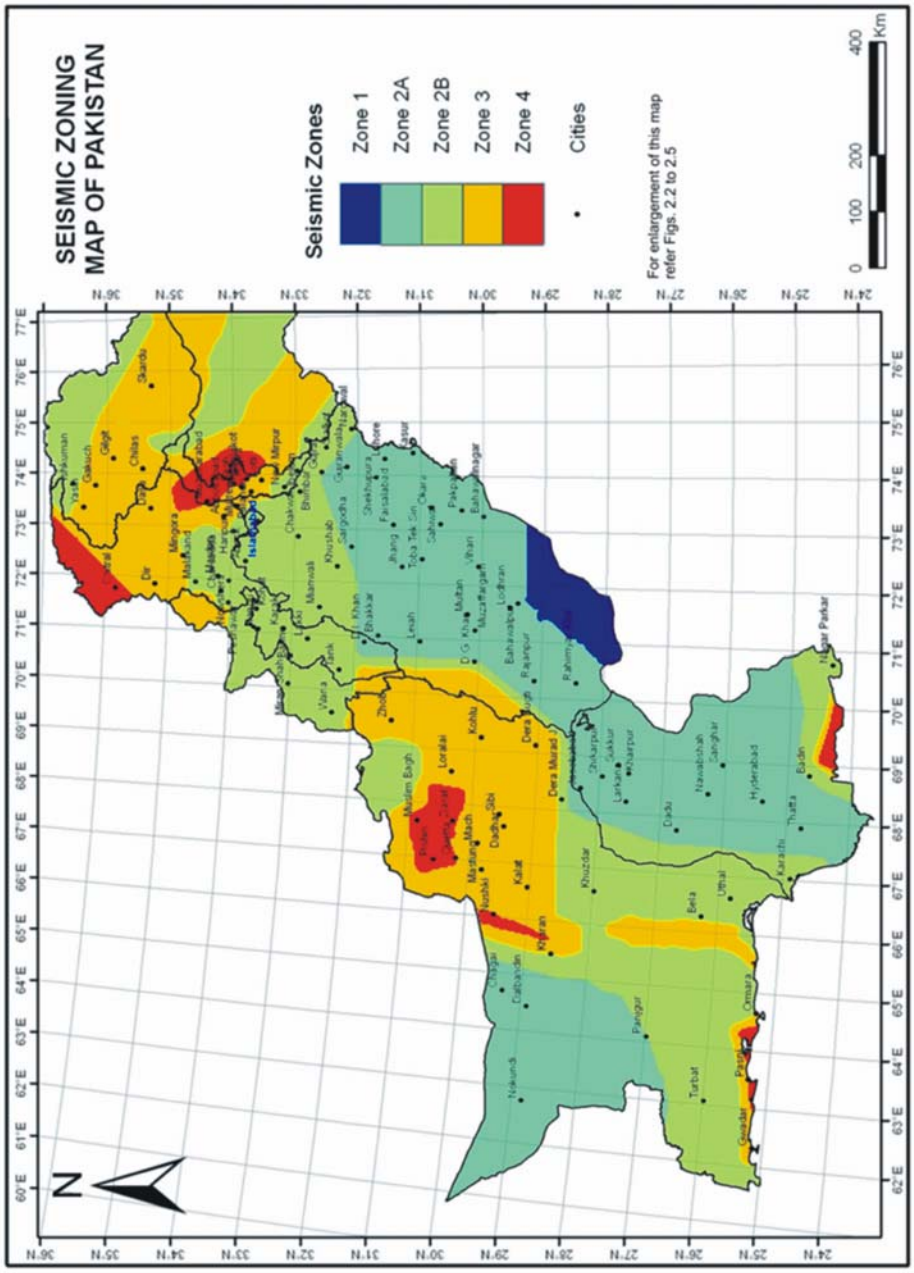


Figure 1: Seismic zoning map of Pakistan.

Construction materials

Cement:

1. Fresh cement is like powder which is usually available in market in sealed bags. On opening the bag, cement starts absorbing moisture from the air and with the passage of time small lumps are formed (Fig.2), as a result of which, strength of cement is reduced. Therefore, the cement bag once opened should be used as soon as possible.

Fig.2: Lumps in cement

2. The lumps in the cement also appear if their sealed bags are stocked for a long period. The formation of lumps in the cement is one of the major indications of old cement. The use of such cement should be avoided.
3. Always use a trusted brand of cement with good quality and avoid the use of substandard cement.

4. Tests can be carried out to assess the strength of cement. This facility is available in all the engineering universities of Pakistan and most of the governmental and non governmental organizations involved in construction activities.

Sand, Khaka and Crush

1. Sand, Khaka and Crush should be clean from soil particles and vegetation. The presence of such impurities reduces the strength of concrete and mortar.
2. Always prefer the gravel (crush) obtained from crushing machines.(Fig.3)
3. The gravel (crush) should be well graded, containing aggregates of different sizes in proper proportions. Concrete prepared from gravels having one size is relatively weaker.

Fig.3: Gravel obtained from crushing machine

4. The size of gravel used for the preparation of concrete should be less than ¾ inches (19mm).

5. Khaka is sand like material obtained from the crushing plants during the crushing of stones. Khaka, if free from soil particles, when used in the mortar for the construction of masonry walls, is not harmful.

Water

1. Drinking water should be used for the preparation of mortar and concrete because the use of contaminated water would result in a significant reduction in the strength of mortar and concrete.

Bricks

2. Always use A-class bricks in the masonry walls.(Fig.4)
3. All the bricks should be of the same size. (Fig.4)
4. The brick should be properly burnt. The edges and corners of the bricks should not be deformed or damaged.

Fig.4: First Class Bricks

5. The quality of bricks can be assessed by striking two bricks against each other. The striking of two A-class bricks against each other would result in a metallic ringing sound. Moreover, if this kind of brick is dropped from a height of 4 feet on hard ground, it does not break. (Fig.5, 6)

Fig.5: Striking of two bricks with each other

Fig.6: Dropping of brick from 4 feet height

Concrete Blocks:

1. The blocks used in the construction of masonry walls should be constructed of concrete with a ratio of 1:4:8 which mean the use of one bag of cement, two wheelbarrows of sand (Picture 7) and four wheelbarrows of crush. If this proportion of sand and crush is exceeded, the blocks constructed of such concrete would be very weak. The use of such blocks in the construction of masonry may prove to be dangerous.

Fig.7: Sand filled wheel barrow

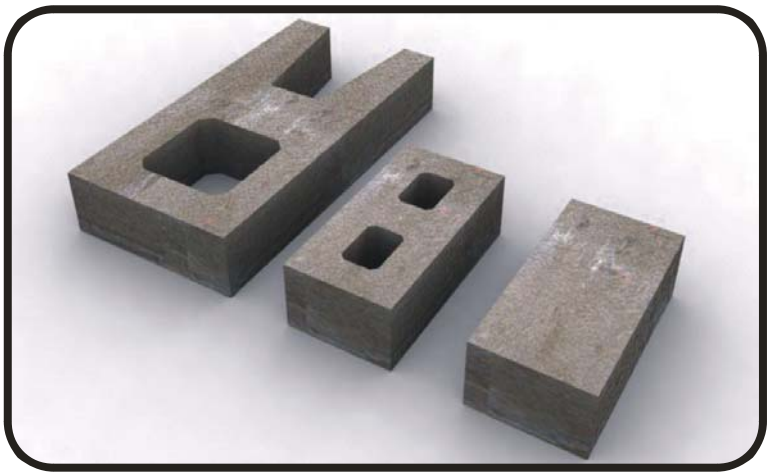


Fig.8: Concrete Blocks

2. If the amount of cement used in the construction of the concrete blocks (with proportions described in 1) is one bag (50 kg) and there is no moisture in the sand and crush, then the amount of water used for its mixing should not be more than 5 to 6 oil tins of 5 kg (figure 9). If sand and crush already contain moisture, the amount of water used for mixing of concrete should be further reduced. Remember the use of excess water in concrete is very dangerous.

3. The use of blocks that are cracked, warped or having broken edges and corners should be avoided.

Fig.9: Five Kg oil tin to measure water for mortar and concrete

Steel

1. Steel free from rust and oil should be used.
2. If large quantity of steel is to be used, it should be tested for its properties from a reputed organization. All the engineering universities in Pakistan as well as most of the governmental and non governmental organizations involved in construction activities have the facility of steel testing. (Fig.10)

Fig.10: Construction material testing machine

Mortar

1. Cement, sand and water to be used in mortar should be according to the instructions described in the previous pages.
2. Constituents of mortar i.e. cement, sand or Khaka should be thoroughly mixed in dry form two to three times, followed by a gradual addition of water in small quantity and remixing.
3. Do not add water at a time so that during mixing, cement water may not be washed by bleeding.
4. Mortar should always be prepared on clean and metalled floor.
5. Use such amount of water in mortar so that the mortar produced is easy to use.. Remember the use of extra (excessive) water reduces the strength of mortar significantly.
6. When water is added to the already mixed cement and sand, then, cement combines with sand and takes the form of glue that is used to bind two things. This is commonly called as mortar. Similar to glue (or Elfy), which becomes dry and useless when not used immediately after removal from its container, mortar also dries up and becomes useless if not used within one hour of its mixing. Thus it is very important to use the mortar within one hour after the addition of water to it. Masonry walls constructed of mortars in which water has been mixed for more than one hour prior to its use may prove harmful (dangerous).

7. The ratio of mortar for plastering should be 1:4 which means the addition of one bag of cement to two wheelbarrows of sand (Picture 7). The masonry walls should be thoroughly soaked with water before the application of plaster.

Concrete

1. Cement, sand, crush and water for use in concrete should be according to aforementioned instructions.
2. The constituents of concrete should be mixed with the mixer (Fig.11). In case of non availability of mixer, the dry constituents should be mixed three to four times with the help of shovels followed by gradual addition of water and subsequent remixing.

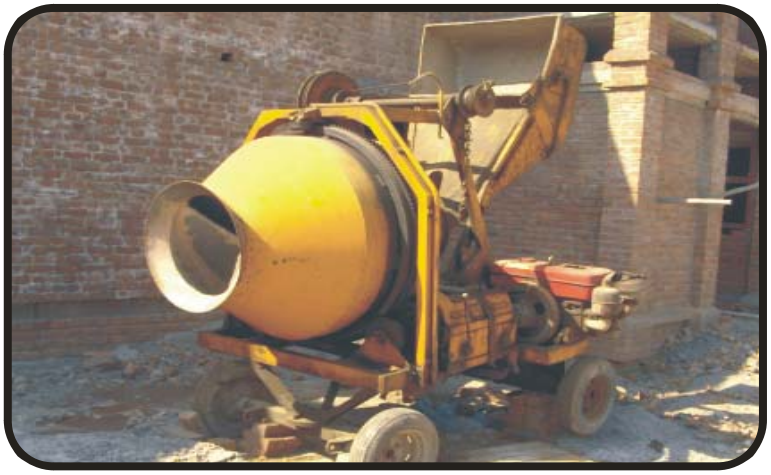


Fig.11: Concrete ingredients/constituents mixing machine

3. A simple way to assess the quantity of water in concrete is to press the wet concrete in hand. In case of good quality concrete, the cement slurry does not flow out between the fingers. (Fig.12)
4. When cement, sand and crush are thoroughly mixed together and water is added, the cement combines with water to form a glue type substance. Just like glue (or Elfy) that dries and loses its effectiveness when not used shortly after removal from their container. Similarly concrete, when not used within one hour after its

mixing with water, would become dry and useless. Thus it is very important to use the concrete within one hour after water is added to it. If more than one hour passes after the concrete is mixed with water, the beams, columns and slabs constructed of such a concrete would be weak.

5. If it happens to use concrete by dropping from a height, the height of fall should not be more than 6ft (Fig.13), because it leads to segregation of concrete which causes severe reduction in its strength.
6. Concrete should be compacted with the help of a vibrator (Fig.14) after placing each layer of 1 to 2 feet when pouring beams, slabs or columns. Remember that strength of vibrator compacted concrete is much more than that of non compacted concrete. If a vibrator is not available than compaction can be done by tamping it with a thick steel rod.
7. All the concrete members such as columns, beams and roof slabs should be kept wet by pouring water for fourteen days.

Fig.12: Pressing of concrete in hand

Fig.13: Falling of concrete from a height

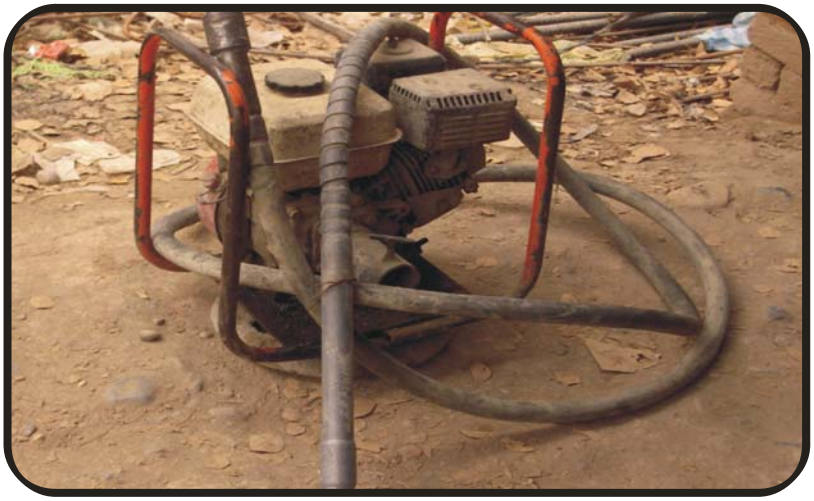


Fig.14: Vibrator

INSTRUCTIONS FOR FIRED CLAY BRICKS OR SOLID BLOCKS MASONRY BUILDINGS

The previous chapter (chapter 2) deals with the instructions about the construction materials that are used for the construction of residential buildings whereas this chapter (chapter 3) instructs on the construction of the different components of residential buildings. These instructions are categorized into two parts: the general instructions and special instructions. The general instructions include the Site selection, Shape, Foundations, Wall construction and the size of windows and doors. Whereas in special instructions, the principles regarding major earthquake resisting elements i.e., beams and pillars are discussed.

General Instructions

Site Selection

1. Avoid construction near an unstable slope, because unstable slopes are prone to slip during an earthquake.(Fig.15)

Fig.15: House collapsed due to slipped slope during earthquake.

2. Avoid construction near rivers or any other places where the ground water level is very high. During an earthquake, the buildings constructed in such areas experience settlement of foundations.
3. Foundation of the whole building should be constructed on the same level. The foundation constructed on different levels may lead to settlement of the building (Fig.16)

Fig.16: Building constructed on unleveled foundation leading to its settlement.

Shape

1. The shape of building should be regular. Buildings of irregular shape cannot resist the earthquake forces efficiently (Fig.17)

Fig.17 (A): Irregular shaped building

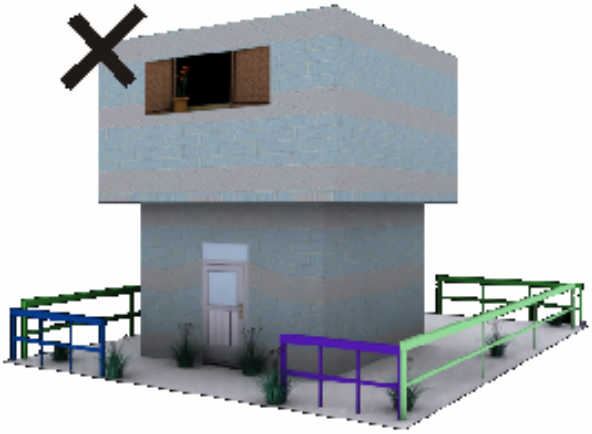


Fig.17 (B): Irregular shaped building

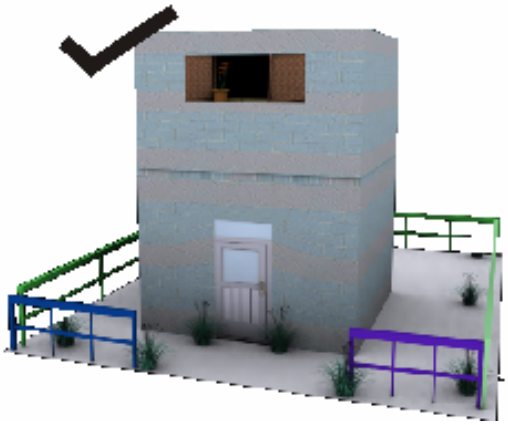


Fig.17(C): Regular shaped building

2. The plan of building should be square or rectangular.
3. The length of a building having rectangular plan should not be greater than 4 times its width.(Fig.18)
4. If due to some reason, the length of plan has to be provided greater than 4 times its width, or the plan is of a complicated shape, then the plan should be sub divided into squares or rectangles (Fig.18)

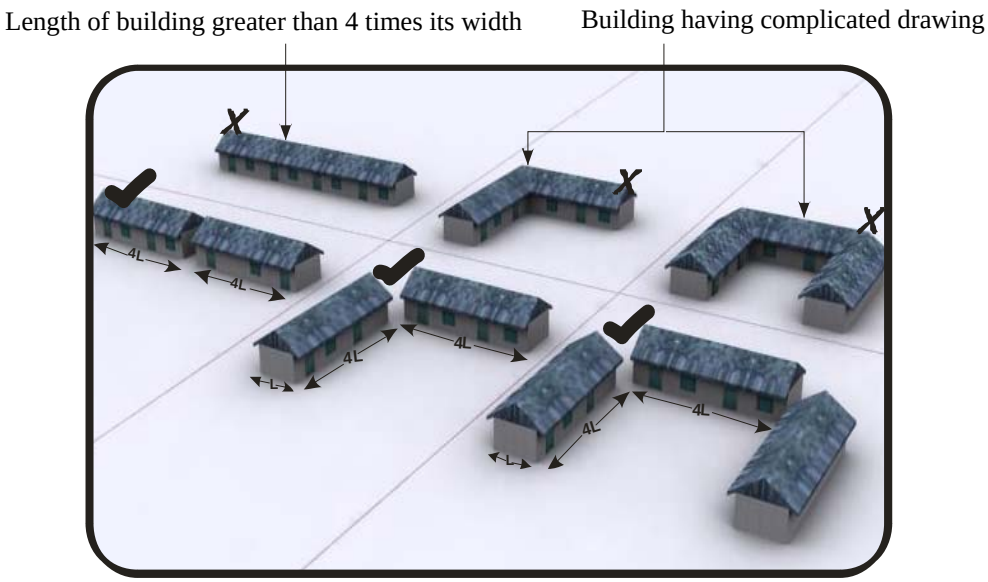


Fig.18: Drawing of building

Foundations

1. The minimum depth and width of foundation should be 3ft (Fig.20) in case of soft soil. If the soil is hard then the depth of foundation may be limited to 1.5ft.
2. After the excavation and leveling of the earth surface, a 6 inch thick concrete pad (1:3:6) should be provided (Fig.20).
3. In case of loose soil, 3 bars of half inch diameter should be provided lengthwise and half inch diameter bars should be provided widthwise at a spacing of 12 inches (Fig.20).

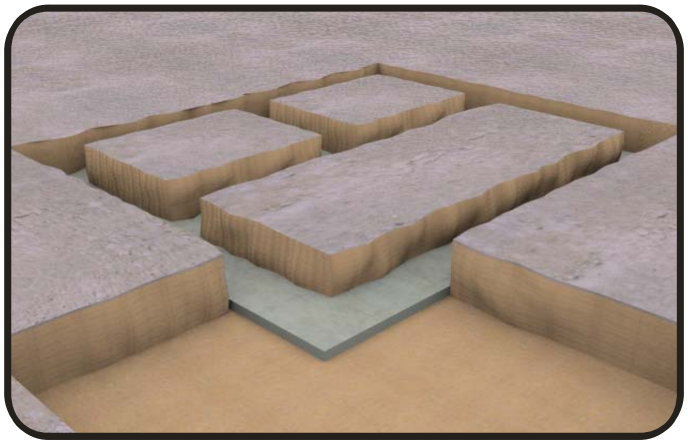


Fig.19: Strip foundation under the walls of the building

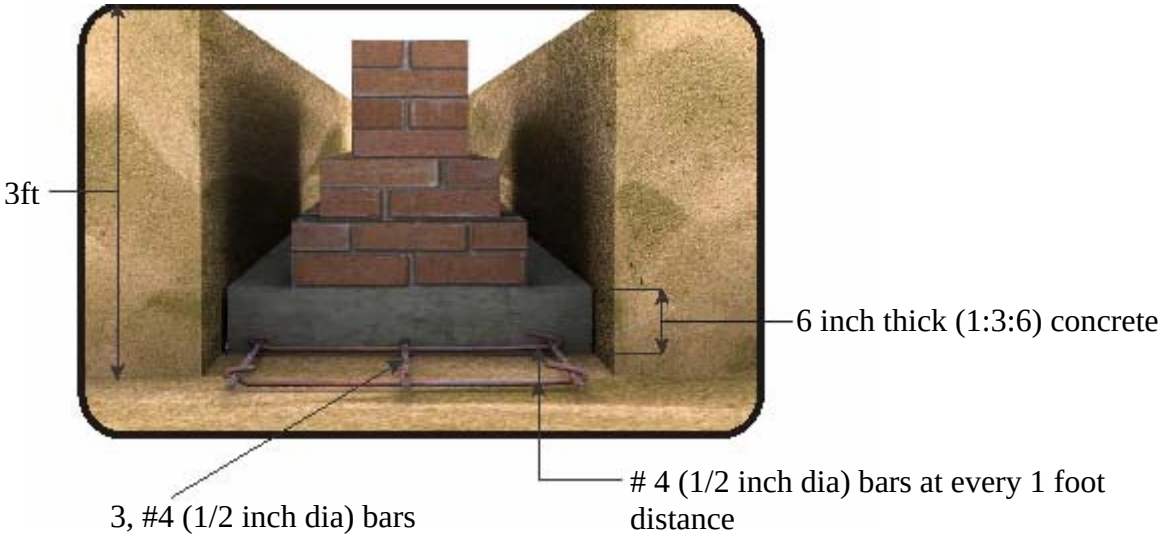


Fig.20: Foundation detail

Wall construction

1. The thickness of brick walls should not be less than 9 inches, while walls constructed of solid concrete blocks can be of 8 inches minimum thickness.(Fig.21)
2. None of the room walls should be longer than 20 feet (Fig.21)
3. The height of each storey in the building should be limited to 10 feet (Fig.21)

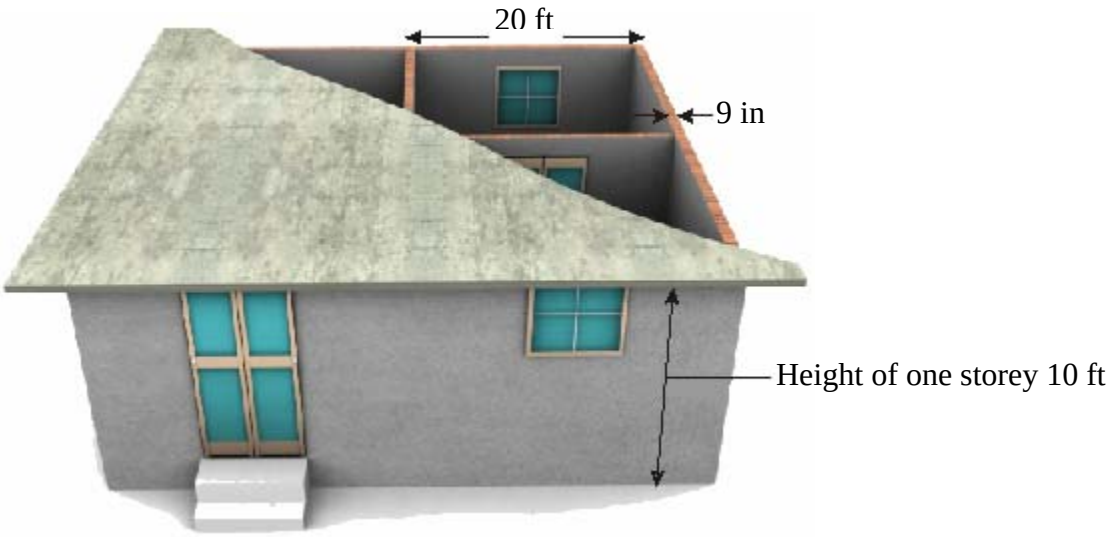


Fig.21: Dimensions of walls

4. The mortar used in the construction of masonry walls should have 1:6 ratio, which means the use of one bag of cement with three wheelbarrows of sand (Figure 7)
5. Some people prepare a large quantity of mortar and use it in several hours, which is a wrong practice. The right practice is to prepare such quantity of mortar which could be used within an hour.
6. Thickness of the mortar joint between two brick courses should not be more than 3/8 inches in any case. The use of thick mortar would result in weak walls (Figure 22)

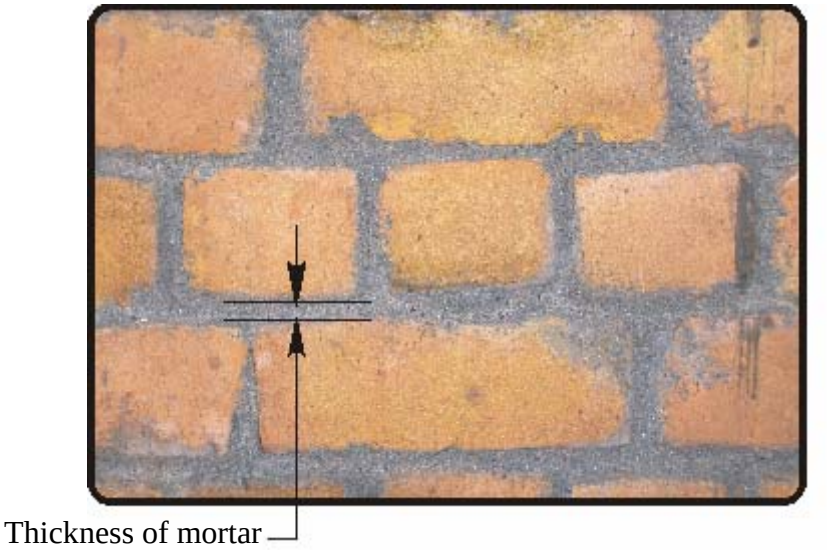


Fig.22: Brick masonry

7. Clay bricks should be kept soaked in water for one to two hours prior to their use. In this way, bricks do not absorb the moisture from the mortar and a strong bond between the mortar and brick is ensured. Whereas concrete blocks need only to be wetted before their use.
8. Minimum 7 days curing is required for masonry work. Use clean, potable water for curing. Remember improper curing may reduce the strength of walls drastically.
9. Curing of plaster on the walls should also be carried out for 7 days.

Openings

1. Provide windows and doors in walls as minimum as possible. If large number of windows and doors are needed, then they should be distributed equally in four walls of the room. Avoid provision of large number of windows and doors in a single wall (Fig.23, 24)

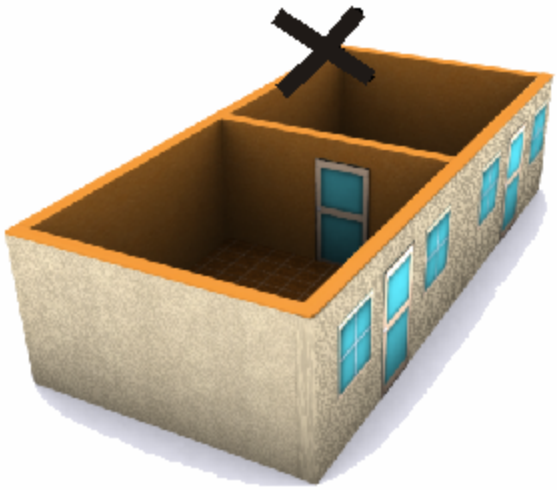


Fig.23: Windows and doors provided in a single wall

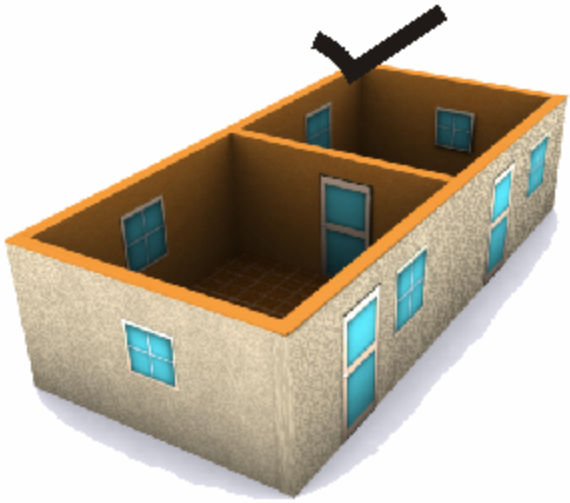


Fig.24: Windows and doors distributed in all the walls

2. Do not provide openings (windows and doors) near the corners of walls.
3. The minimum distance of any opening from the wall corner should be 2.5 feet and the distance between any two openings in a single wall should not be less than 3.5 feet (Fig.25)
4. The total width of all the openings, provided in a single wall, should not be more than 40% of the total length of wall. For example, if the total length of wall is 15 feet, then, the total width of all the openings should be limited to 6 feet.
   (Hint: Total width of openings = 0.4 * Total length of wall)

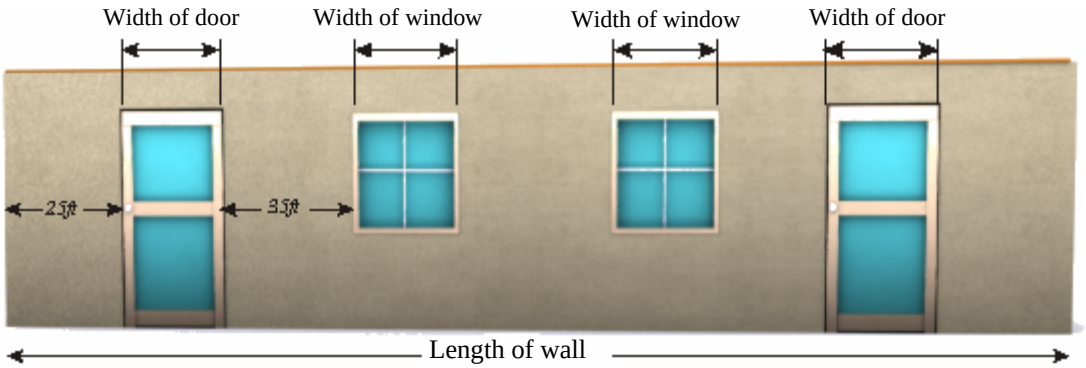


Figure .25 Distances between doors and windows

Special instructions

According to the instructions discussed here, the masonry construction is strengthened by providing concrete pillars at specified locations. The wall and pillars are connected together with the help of concrete beams. By doing so, all the elements of the building are fixed together and the building is able to withstand the earthquake forces efficiently. This type of construction is known as Confined Masonry. The distinctive feature of confined masonry is the construction of walls before the casting of pillars.

Concrete pillars

1. It has been observed that during the earthquake, the corners of the buildings experience major damage (Figure 26), therefore the building corners should be strengthened.

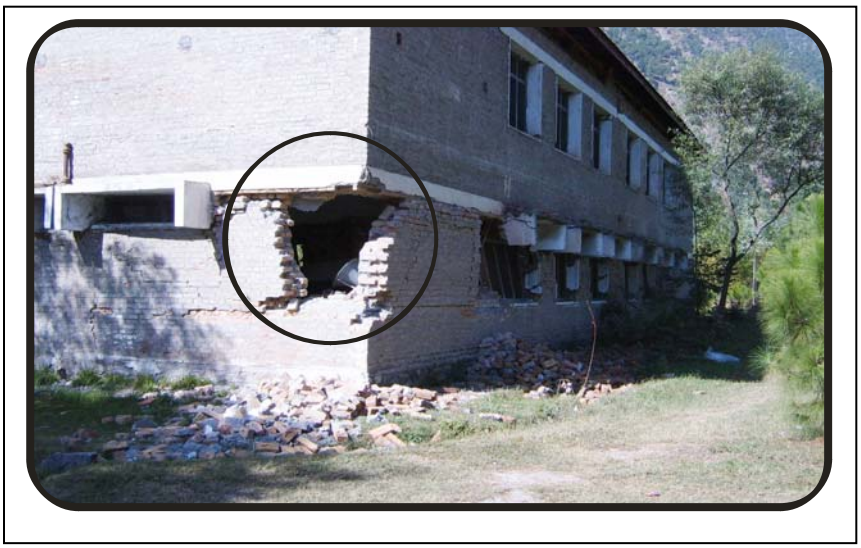


Fig.26: Damaged corner of building due to earthquake

2. According to the methodology of confined masonry, the corners of the buildings and junctions where two or more than two walls meet, are strengthened by providing concrete columns (Figure 27)

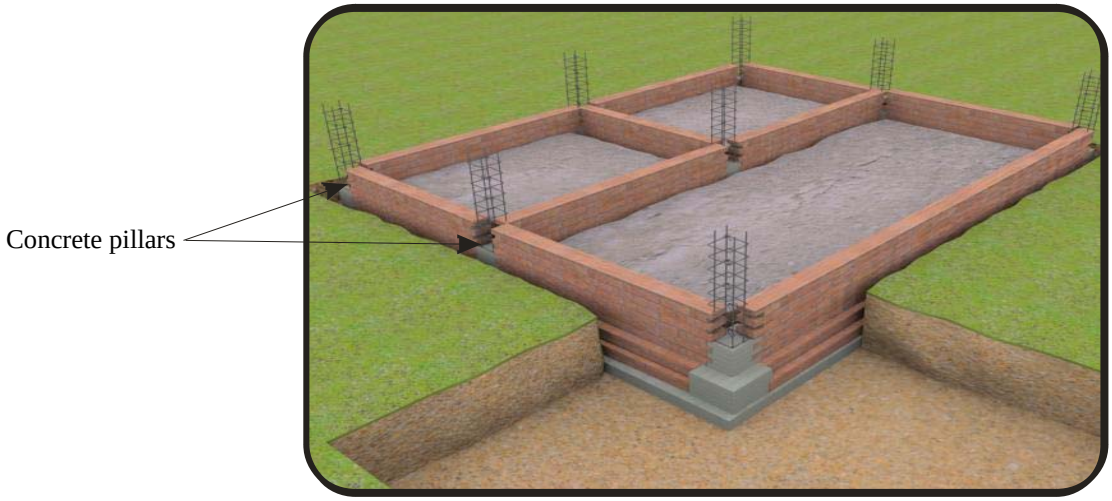


Fig.27: Concrete pillars provided at wall corners

3. In addition, the distance between the two pillars in any wall should not be more than 20 feet.
4. If a Gable wall is also provided in the building and its height is more than 4 feet, then concrete pillars should be provided in the middle and at sides at every 8 feet distance in the Gable wall.(Fig.29)
5. The size of each pillar should be at least 9 x 9 inches. In each pillar, 4 longitudinal bars of ½ inch diameter along with rings of 3/8 inch diameter placed at 6 inches should be provided (Figure 28)

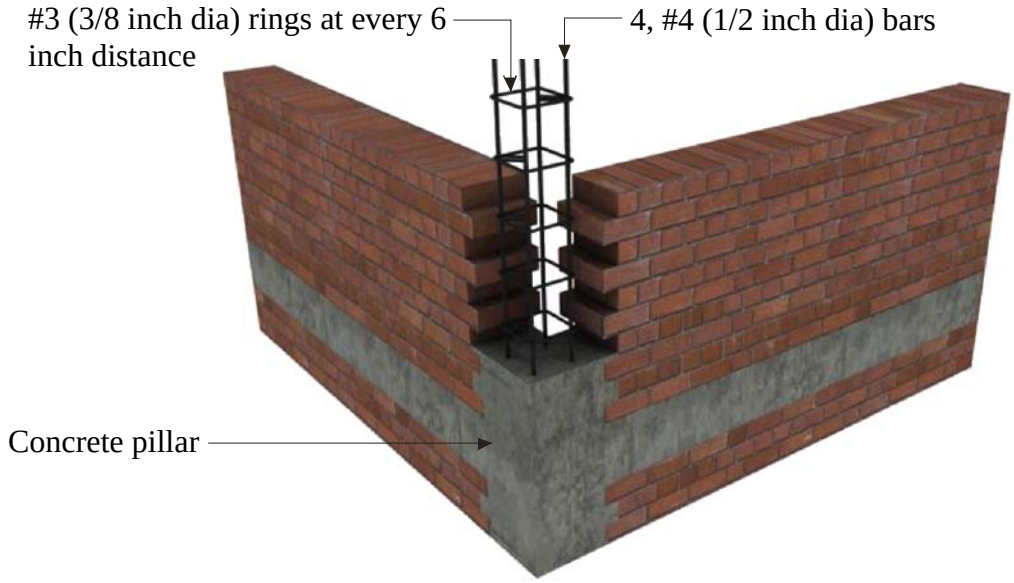


Fig.28: Detail of pillar's reinforcement

6. The concrete used in each pillar should be of proportion (1:2:4) which means using one bag of cement, one wheelbarrow of sand (Figure 7) and two wheelbarrows of crush.
7. Use minimum amount of water in concrete. For the construction of concrete pillars, if one bag of cement (50kg) is needed, and there is no moisture in the sand or crush, then the quantity of water should not be more than 25-30 kg. In terms of 5kg oil tin (Figure 9), the quantity of water should be limited to 5-6 tins with one bag of cement. If sand, crush or both are already wet; the amount of water used for mixing the concrete should further be reduced. It should be remembered that the use of excess water in concrete is very harmful.
8. The concrete used in the construction of the pillars should be compacted with the help of a vibrator after pouring each one to two feet of concrete. Remember that the strength of compacted concrete is very high as compared to uncompacted concrete. If a vibrator is not available, then the concrete may be compacted by tamping it with a thick steel rod.
9. Each concrete pillar should be properly cured for at least 14 days.

Concrete Beams

1. If all the members of the building (walls, pillars act) are not properly interconnected, then the building experiences major damage during an earthquake. According to confined masonry methodology for constructing earthquake resistant buildings, it is vital to provide concrete beams at specified locations in the walls. This helps in binding all the members of the building together, thus enabling it to resist the earthquake forces.
2. In figure 29, three different types of concrete beams are shown. The concrete beam provided at the floor level is generally known as plinth beam or plinth band. The concrete beam provided above the doors and windows is called lintel beam or

lintel band, whereas the concrete beam provided at the roof level is called roof beam or roof band.

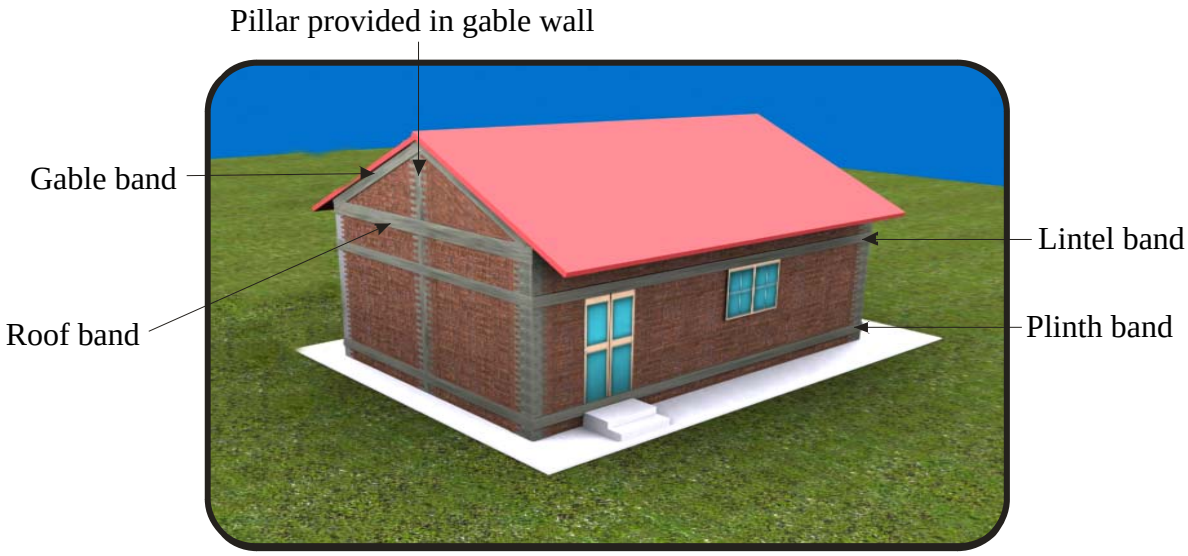
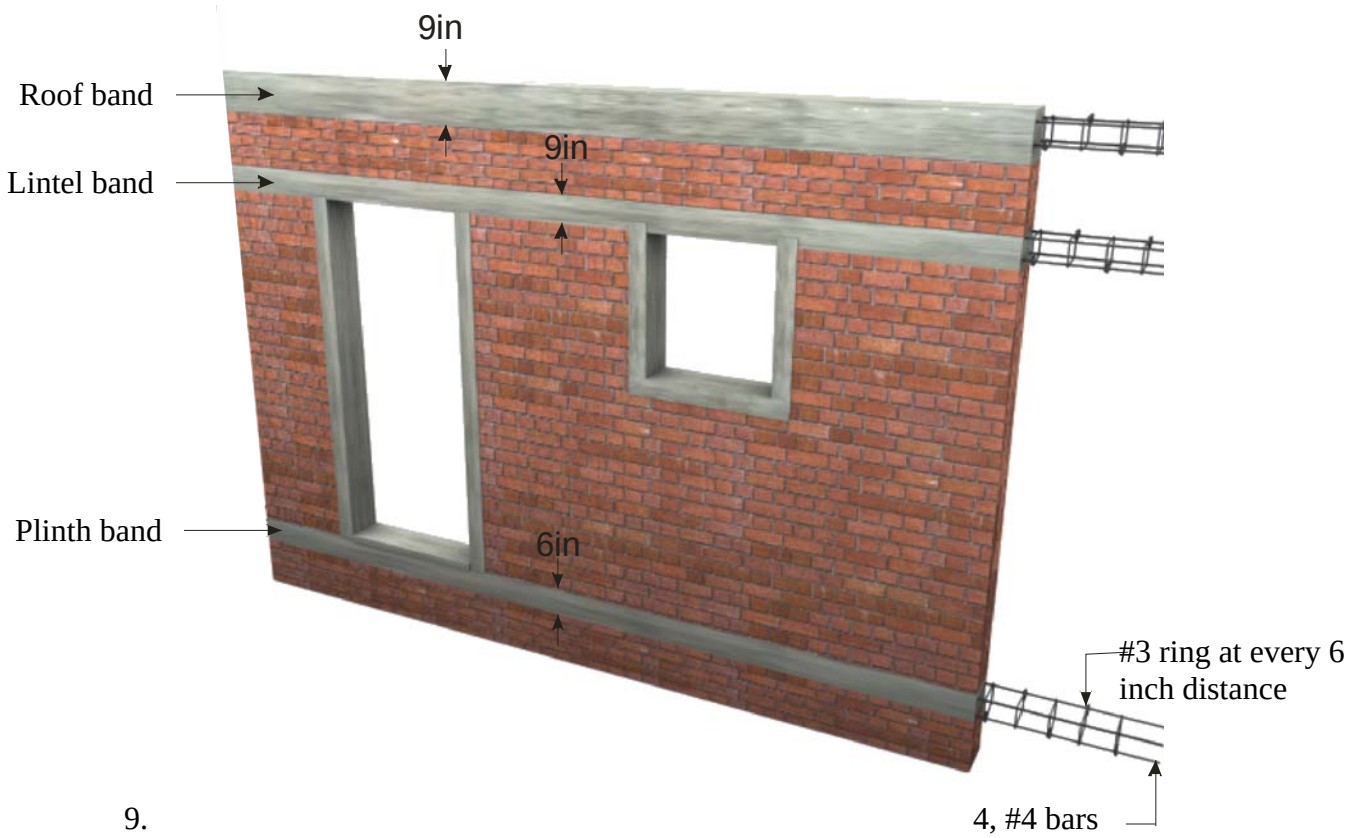


Fig.29: Concrete bands in case of gable roof

Fig.30 Concrete bands provided at specified levels

3. In case of a concrete roof slab, it is not necessary to provide a roof beam, as shown in figure 30. In all the other situations, it is necessary to provide all of the aforementioned beams in the building.
4. When gable walls are provided, it is necessary to provide a gable beam along with the roof beam as shown in figure 29.

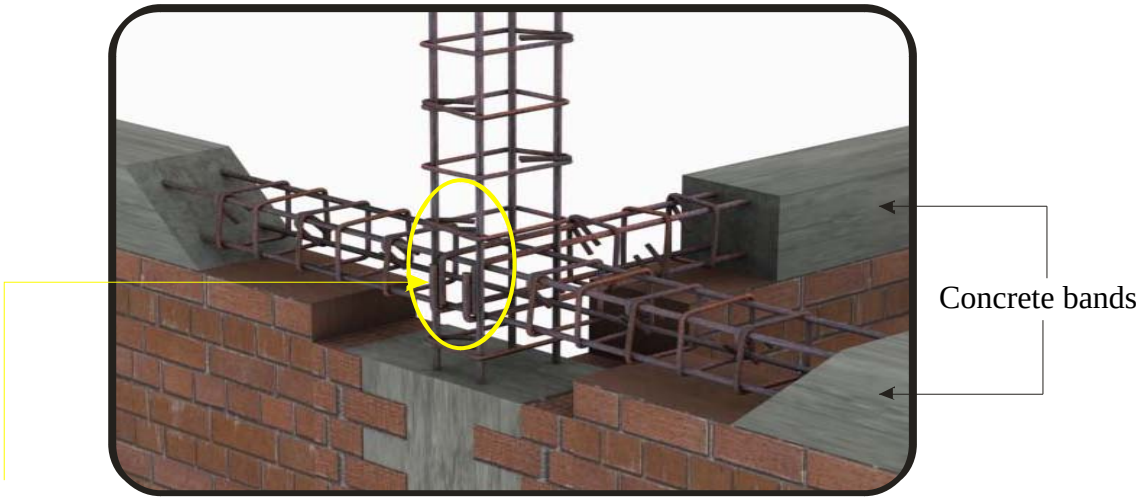
5. The width of all aforementioned concrete beams should be equal to the thickness of wall i.e., 9 inches in case of brick walls and 8 inches in case of block masonry walls.
6. The depths of all the aforementioned concrete beams are shown in figure 31. While laying the lintel beams, care must be taken that they not only span the windows and doors, but like plinth beams and roof beams, they also span the entire length of the wall. In addition, these beams should also be provided in walls which do not have windows and doors as shown in figure 29 and 30.
7. In all beams described above, 4 steel bars of ½ inch diameter should be provided lengthwise along with rings of steel, having a diameter of 3/8 inch, placed at a distance of 6 inch along the length of the beam.
8. If the width of any opening becomes greater than 6 feet, then the depth of lintel beam should be increased from 6 inches to 9 inches and 2 additional steel bars of ½ inch diameter should be provided in the lower part of the beams. This will increase the number of bars in the bottom part of the beam from 2 to 4.



9.

Fig.31: Detail of concrete bands

10. The longitudinal bars of concrete beam should be firmly secured with the steel bars of the column (Fig.32, 33)



Hooks provided at the ends of concrete bands

Fig.32: Connection of concrete bands and pillar

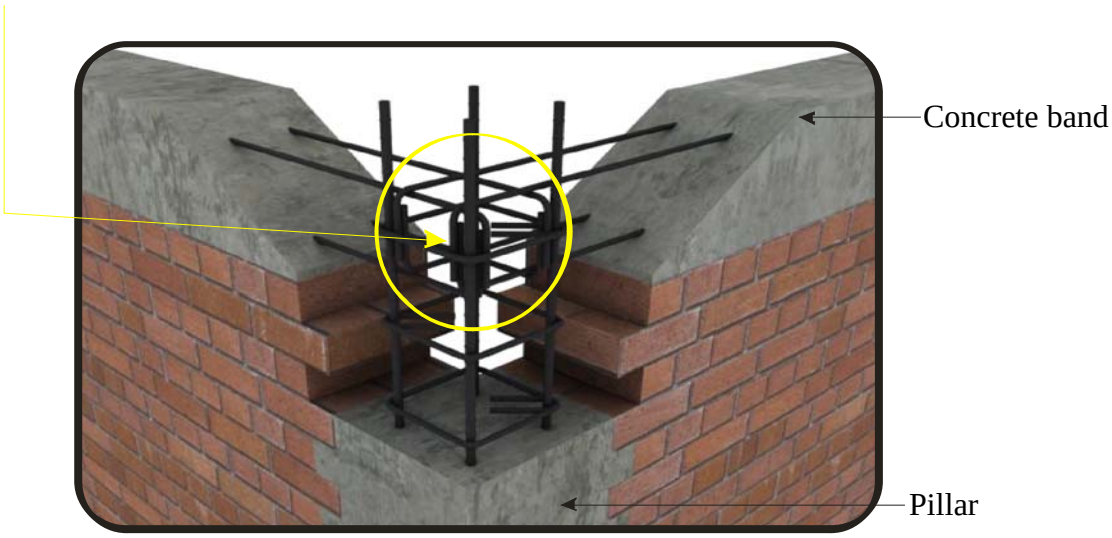


Fig.33: Connection of concrete bands and pillar

11. The concrete used in the concrete bands should be of proportion (1:2:4) which means using one bag of cement, one wheelbarrow of sand (Figure 7) and two wheelbarrows of crush.
12. Use minimum amount of water in concrete. For the construction of concrete beams, if one bag of cement (50kg) is needed, and there is no moisture in the sand or crush, then the quantity of water should not be more than 25-30 kg. In terms of 5kg oil tin (Fig.9), the quantity of water should be limited to 5-6 tins with one bag of cement. If sand, crush or both are already wet; the amount of water used for mixing the concrete should further be reduced. It should be remembered that the use of excess water in concrete is very harmful.
13. Concrete beams should be properly cured for at least 14 days.

RCC Frame around openings

1. All the openings should be enclosed in 4 inches thick RCC frame.(Figure 34)

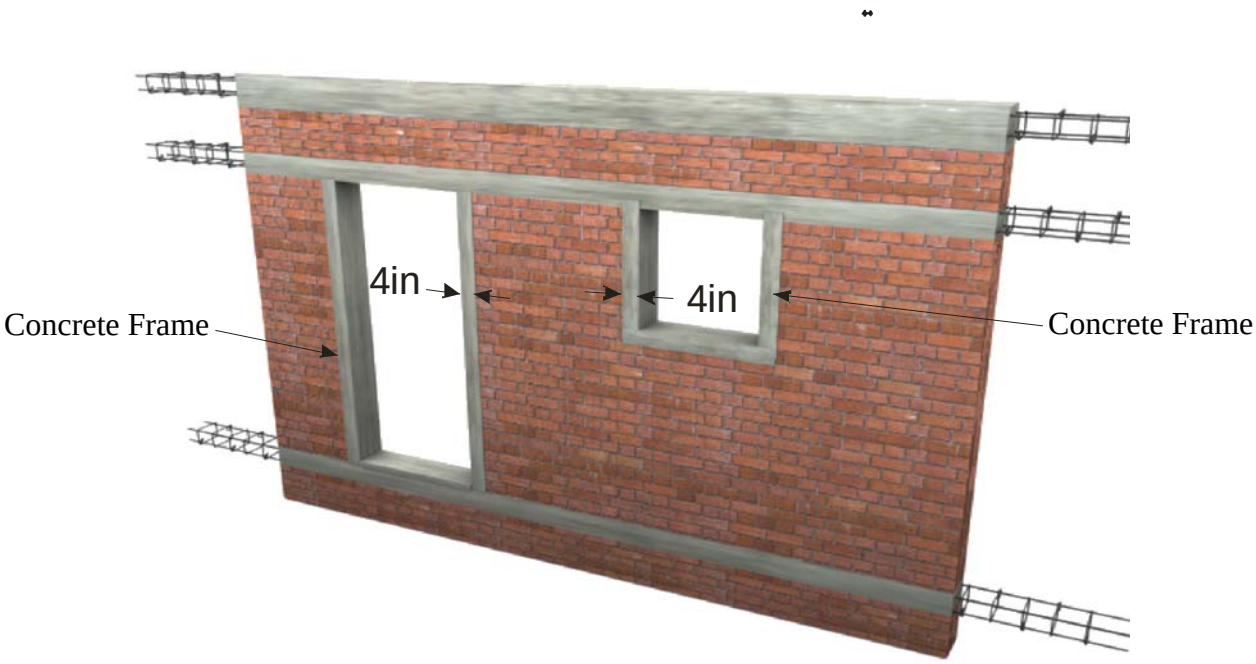


Fig.34: RCC Frame provided around the openings

2. In concrete frames, 2 steel bars of ½ inch diameter should be provided longitudinally along with steel rings having a diameter of 3/8 inch and spaced at 6 inches (Figure 35)
3. The steel bars of the RCC frame should be firmly tied to the steel bars of the lintel beam (Figure 35)

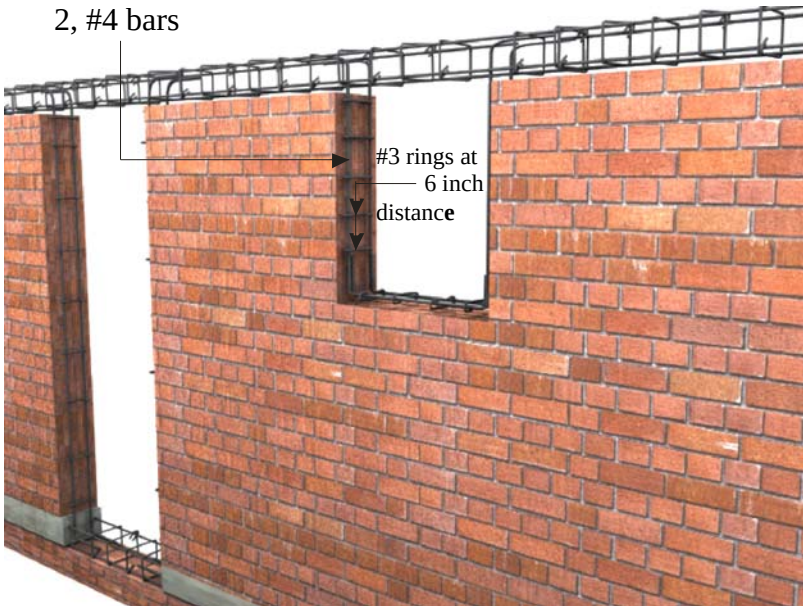


Fig.35: Reinforcement detail of RCC Frame

Miscellaneous Instructions

1. Hooks of the steel rings in the pillars and beams should be at an angle of 135°. (Figure 36)
2. Hooks of the consecutive rings should be at the opposite corners. (Figure 36)
3. Lap in the steel bars should be provided at the mid height of the pillar. (Figure 37)
4. Lap in the steel bars in the beam should be provided at the location as indicated in Figure 37.
5. It is vital to provide hooks in the steel bars at the ends of beams. (Figures 32, 33)

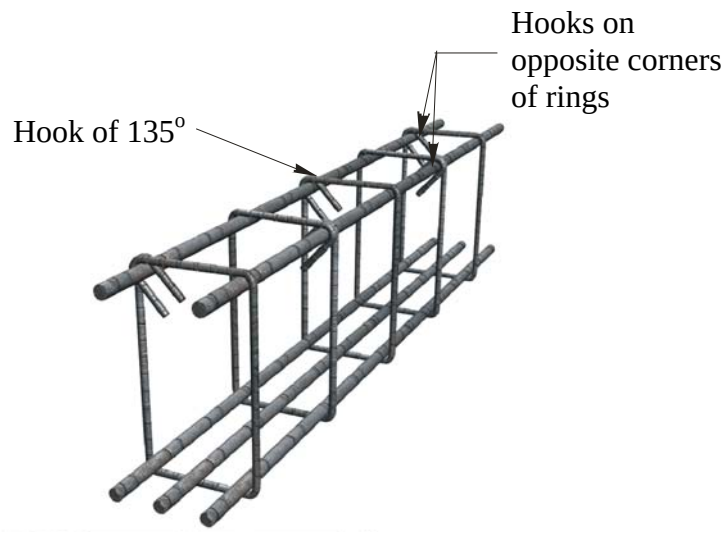


Fig.36: Hooks on the opposite sides of rings

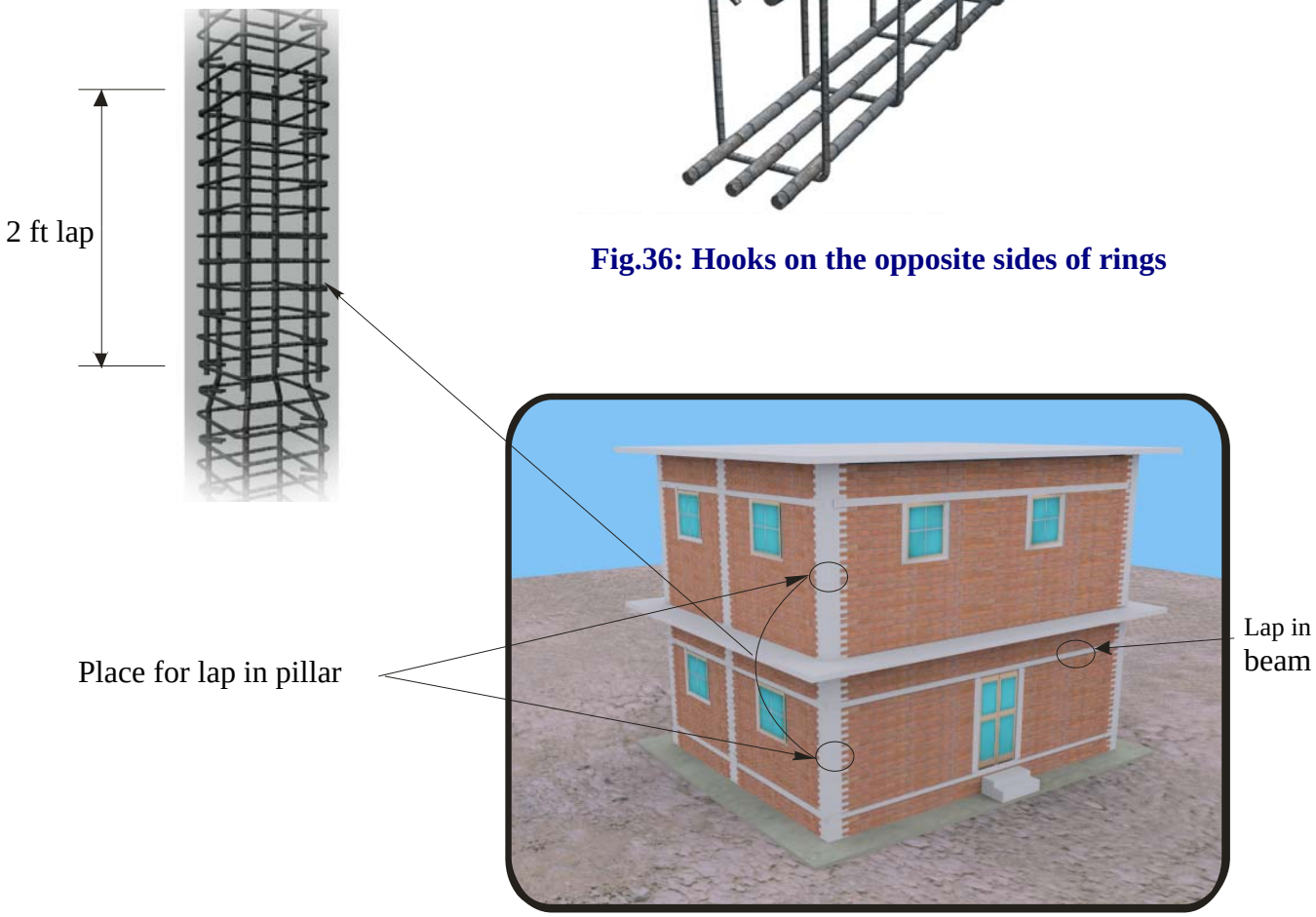


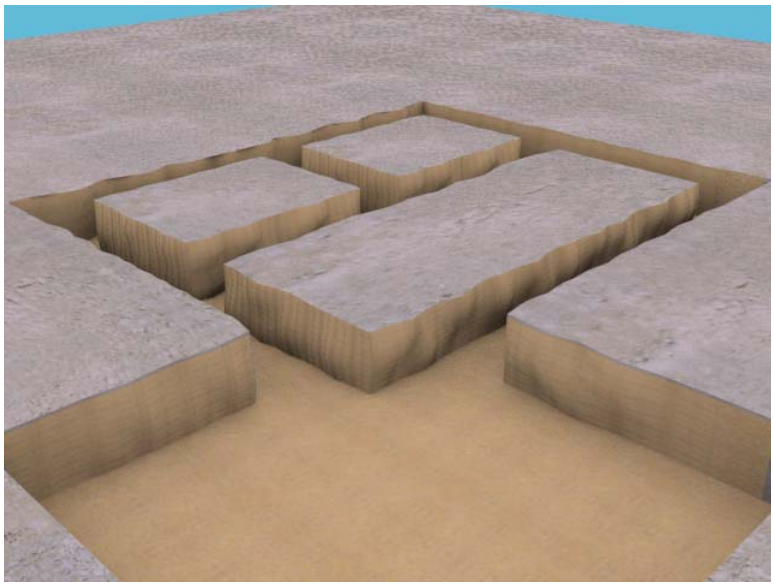
Fig.37: Lap detail of concrete bands and pillars

Some relaxations for buildings of Zone-2:

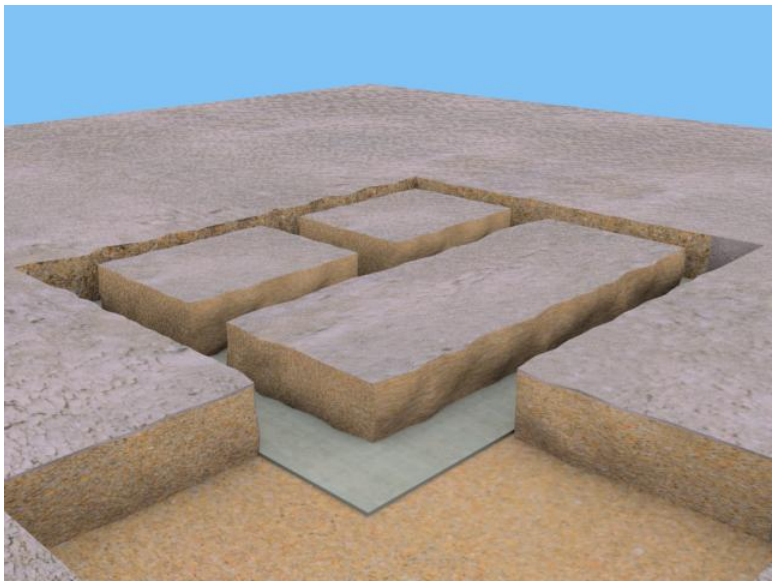
The guidelines for buildings constructed in zone-2 are almost the same as discussed earlier but some relaxations are allowed at some places, as described below

1. The mortar used in the masonry construction can be of ratio (1:8) which means the use of one bag of cement with four wheelbarrows of sand.
2. The unsupported length of any wall / distance between any two pillars can be increased from 20 feet to 25 feet (Fig.21)
3. The minimum distance of any opening from the wall corner can be 2 feet instead of 2.5 feet (Fig.25)
4. The minimum distance between any two openings, provided in a single wall, can be 3 feet instead of 3.5 feet (Fig.25)
5. The total width of all the openings, provided in a single wall, can be increased to 50% instead of 40% of the total length of wall. For instance if the wall length is 20 feet, then, the overall width of openings can be limited to 10 feet (Fig.25)
6. It is not necessary to provide RCC frame around the openings in zone-2.(Fig.34)

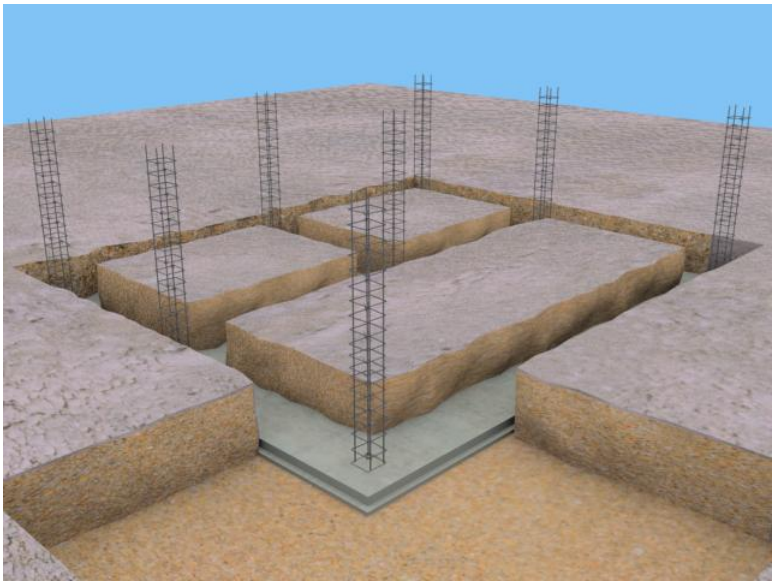
STEP-WISE CONSTRUCTION OF CONFINED MASONRY



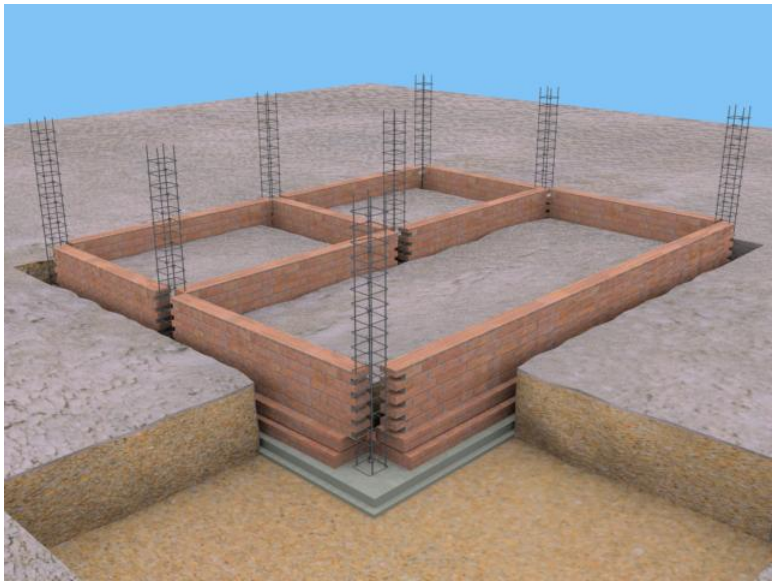
Level the bed of the foundation after excavation.



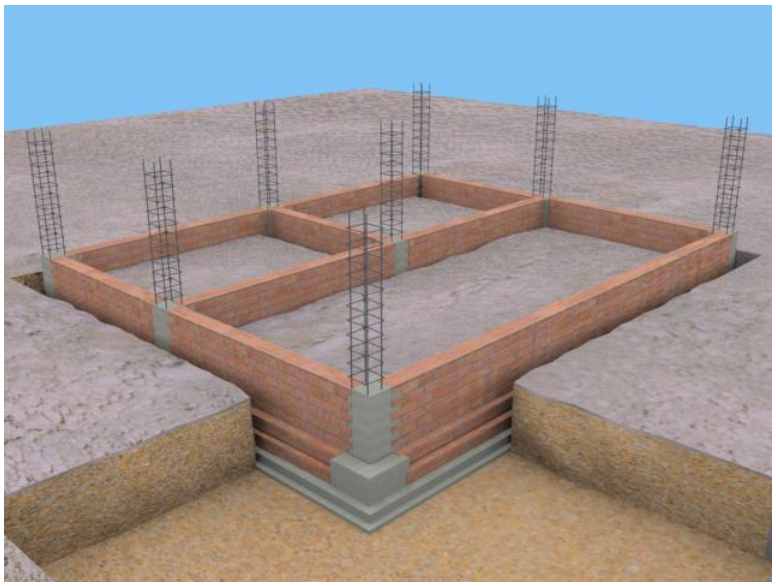
Pour 1:4:8 concrete at the bottom of the foundation. The thickness of the concrete should be 4 inch and it should have a level surface.



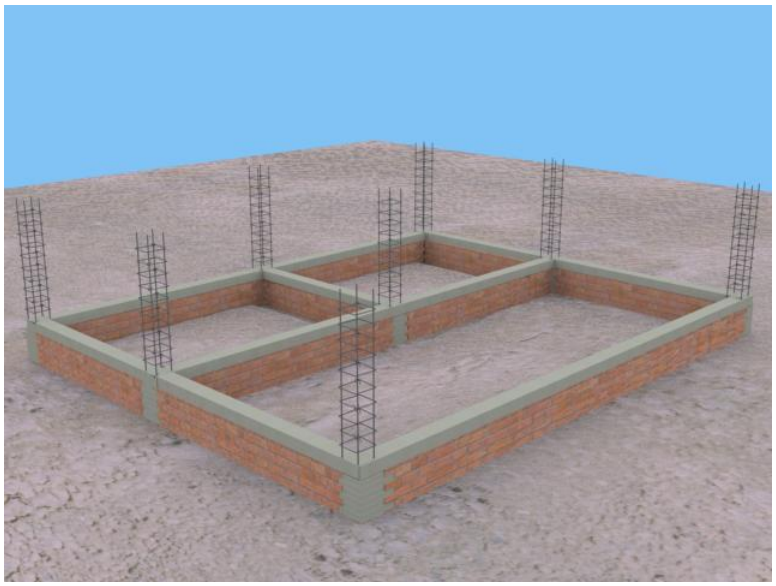
After tying the reinforcement of pillars and foundation, pour 1:3:6 concrete in the foundation having a thickness of 6 inch. Due care must be taken while tying the reinforcement of the pillars to ensure that the lap is provided at the middle of the first storey.



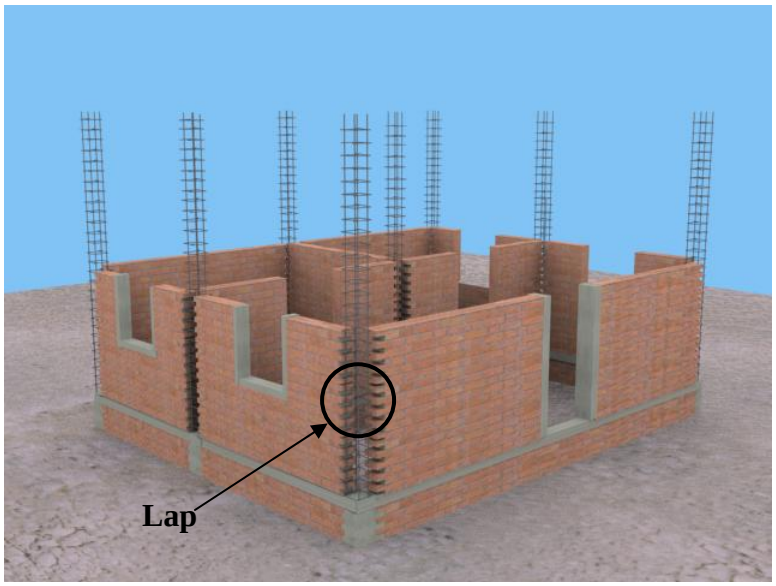
Construct the walls upto the plinth level and provide gaps at the locations of the pillars.



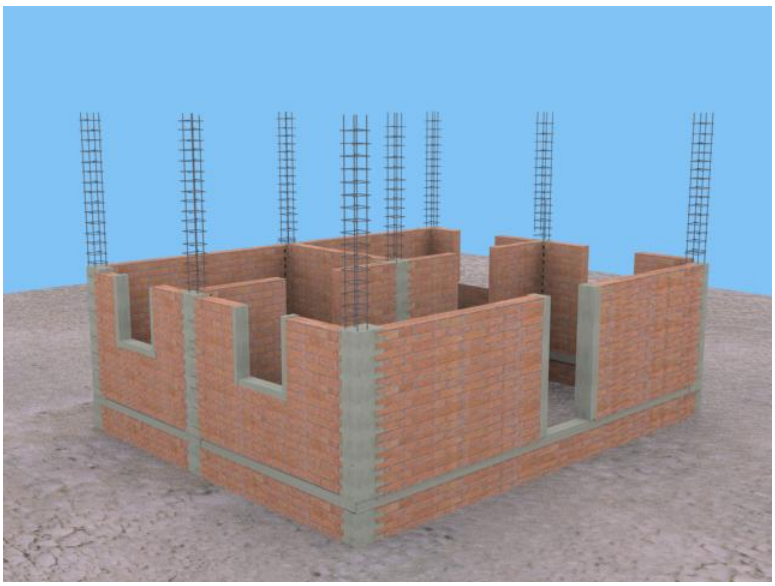
Pour concrete in the pillars upto the plinth level.



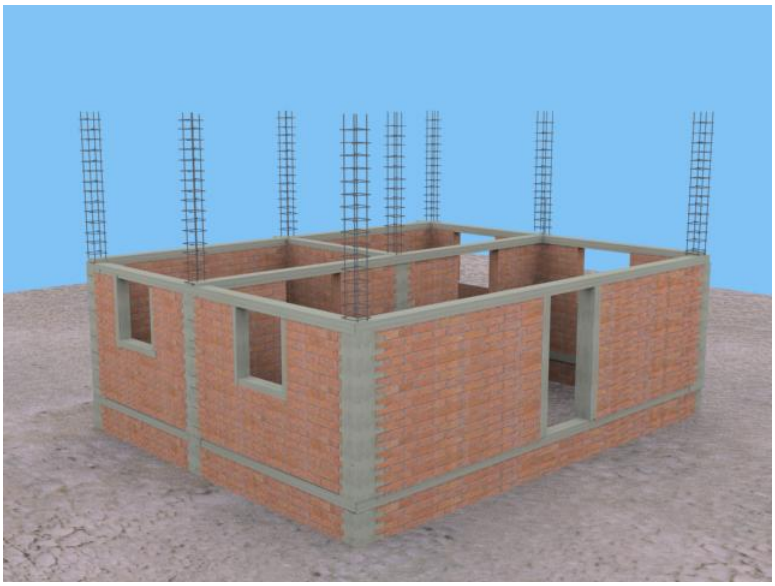
After tying the reinforcement of the plinth beams, pour concrete in the plinth beams.



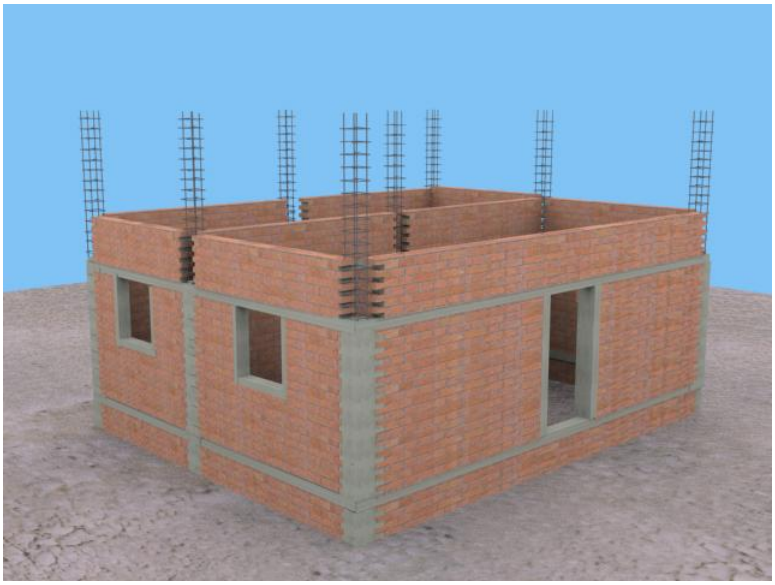
Construct the wall upto the lintel level while leaving gaps for the pillars. Extend the reinforcement of the pillars further. In case of construction of second storey in future, the length of the pillar reinforcement should be such that to ensure a lap at the middle of the second storey.



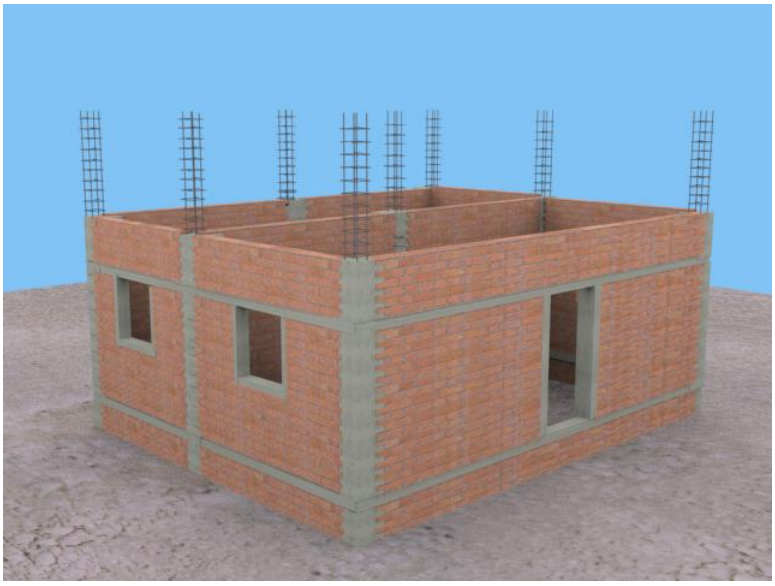
Pour concrete upto the lintel level.



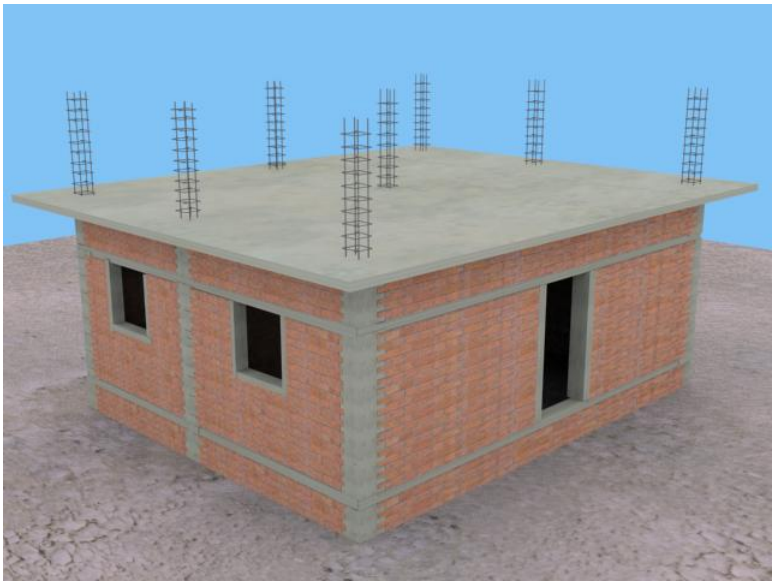
After tying the reinforcement of lintel beams, pour the concrete of lintel beams.



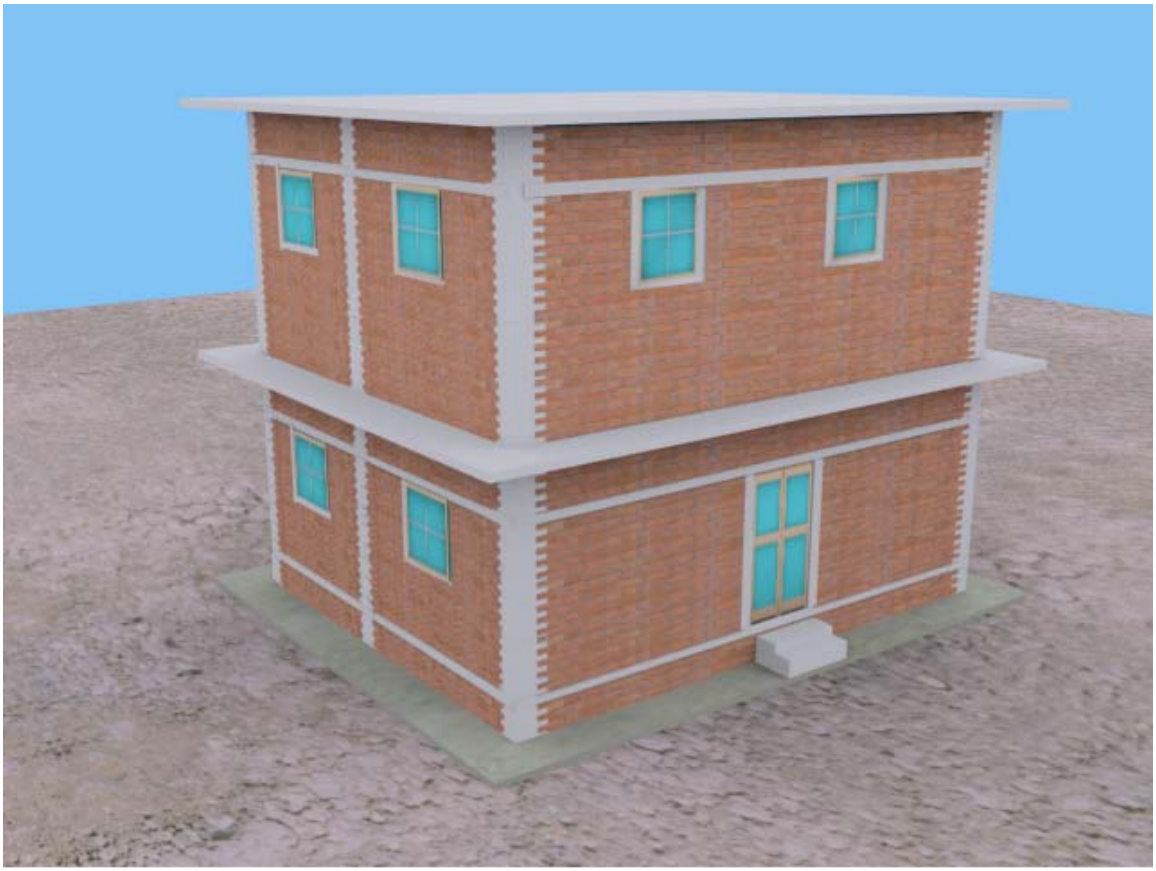
Construct the walls upto the roof level and leave gaps for the pillars.



Pour concrete in the pillars upto the roof level.



After tying the reinforcement of the slab, pour the slab concrete.



Construct the second storey similar to the first storey in a step-wise procedure.