3. COHERENCE OF THE ENTIRE CONSTRUCTION

The "hanging together" of the entire construction is important to withstand long-lasting earthquakes.

- All walls should be connected together at the corners.
- Internal cross-walls, including walls of sanitation units, stores and wardrobes, can assist in the overall stability of the building.
- All floors and roofs should be connected to the walls.
- Floors should be lightweight and function as diaphragms.
- Walls should not have long unsupported fields.
- Piers between openings should be adequately strong.
- When piers between openings are very small, they should be designed as columns.

The stability of the house not only depends on the reinforcement of individual wall sections, but largely on the overall coherence of the construction. Walls that are twice as long as high (one storey) need to be supported with reinforced buttresses or stabilising cross-walls into which these long walls are anchored. Cross-walls can be part of sanitation units, storage rooms or wardrobes. All floor and roof beams need to be properly anchored into the walls and the wall tie-beams to create floor/roof diaphragms that function in two horizontal directions. All inside walls need to be anchored into this floor/roof diaphragm as well.

In the left drawing below, the floor beams are all anchored into the opposing walls and work together as a result of the nailing of the floor boards[6]. However, due to lack of connection of the floor-plane to the side walls, the two connected walls will cause large stress forces in the corner of the building.

The right drawing shows that the floor diaphragm transfers the forces to the side walls, in the plane of the wall. With such a design, the construction as a whole has a much larger resistance.
The vertical connection of the wall with the floor beams and side anchors should be coming up from the tie-beam or lintel beams. The use of 3mm galvanised wire for these anchors is recommended.

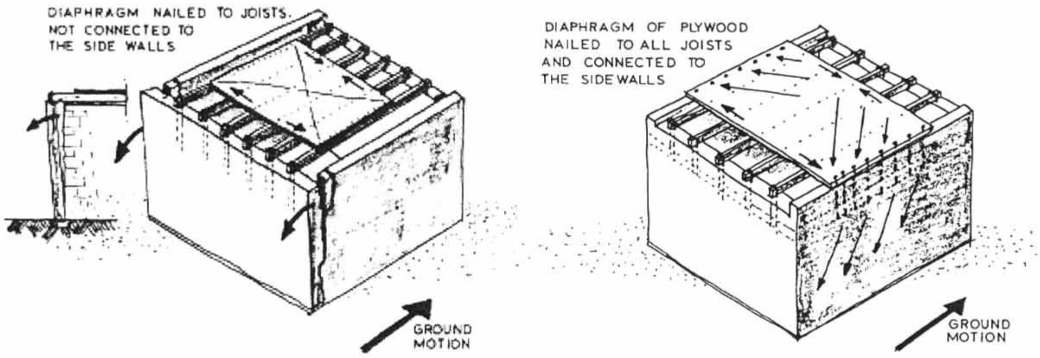

FIGURE 13. ROOF DIAPHRAGM FIXED TO ONLY TWO WALLS OR TO ALL FOUR WALLS

The use of floor diaphragms is required for all buildings up to three storeys (30 ft.) that obtain their stability from the load-bearing walls. The higher the building is, the greater the amount of

[6] As an alternative to the floor boards, roof sheeting can be applied or roof sheets with a light concrete floor (see Chapter 5).

reinforcement required in the lower walls of the building. The influence of good floor diaphragms that transfer the horizontal forces to internal and external cross-walls is very important. In addition, for high buildings (three storeys) the amount of shear walls in the lowest part of the building should be more than in the top floors.

The window and door openings should be distributed in the façade in such a way that sufficient wall segments or piers remain to form shear wall sections. For non-engineered constructions the total section of piers can be reduced in the higher floors as compared to the lower floors. This means that when a building is planned to be two or three storeys high, but will be built in stages (in several years), the amount of piers and internal wall reinforcement should match the highest design of the future.

The following rule-of-thumb directions assure sufficient safety to withstand minor earthquakes.

◊ No window or door opening should be made within 3 ft. of the corners of the building.
◊ If a wall section between windows and door openings is smaller than its height, then the vertical sides of these wall sections need to be extra reinforced (three vertical "ladders").
◊ If piers are 2 ft. or smaller, they should be designed as columns.
◊ For the final top floor of the building, where there will be **no future constructions above**, the cross-section of the shear wall segments should be a minimum of 40% of the original wall section (without the openings).
◊ For the floor of the building where there will be only **one floor constructed above**, the cross-section of the shear wall segments should be a minimum of 50% of the original wall section (without the openings).
◊ For the floor of the building where there will be **two floors constructed above**, the cross-section of the shear wall segments should be a minimum of 60% of the original wall section (without the openings).
◊ When the openings in the lowest floor (of a three-storey unit) consists of more than 30% of the original wall construction, then column constructions need to be realised.
◊ Only in cases where the inside and outside walls consist of a fully connected network bound by tie-beams and floor diaphragms, and the distribution of the shear walls is evenly in two directions, then the percentages indicated above can be taken over the entire wall section of that floor. In traditionally built houses with poor connections between floors, beams and walls, this is almost never the case.

The following drawings give a schematic presentation of the information provided above.

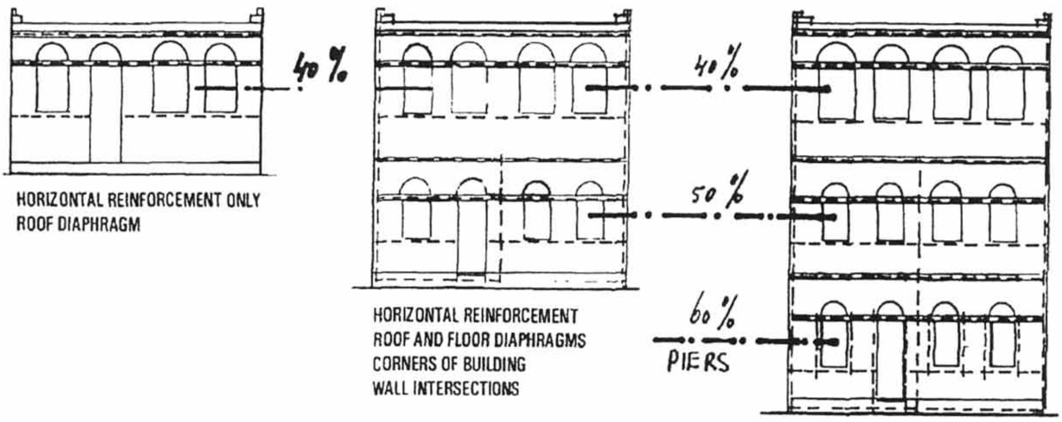

FIGURE 14. MINIMUM PERCENTAGE OF WALL SECTIONS AND PIERS REQUIRED FOR LOW BUILDINGS

4. BASIC STRENGTH CALCULATION

The BACIP wire-mesh reinforcement technique can be applied in any wall construction, be it stone construction, cement blocks or adobe walls. The wire-mesh should be placed in alternating layers in non-masoned constructions to ensure that all stones in the construction are connected to the wire-mesh strips. The better the connection between the stone masonry and the wire-mesh, the stronger the construction will be.

> **WARNING:**
>
> If the wire-mesh is fitted into a loosely masoned wall construction or laid between stones that do not fit tightly around the wire-mesh, it will not make the wall stronger. It is only in combination with good masonry and/or stone cutting work that the wire-mesh greatly enhances the earthquake resistance of the wall[7].
>
> The wire-mesh resists only the stress forces in the construction. The compression forces need to be taken care of by good quality stone or masonry work. The friction between stone and wire-mesh is enhanced with cement mortar.
>
> **A wall of rubble before an earthquake will be a pile of rubble after an earthquake – with or without reinforcement.**

The warning above indicates that the wire-mesh wall reinforcement works best with good stone masonry work. The quality can be increased with pointing the inside and outside faces of the stone wall with cement mortar of a sand : cement mix of 10:1. Filling the interior of the wall with mortar is not necessary.

When constructing load bearing walls with compacted earth blocks, these are masoned in full clay soil mortar, thus providing sufficient adherence to the knots in the wire-mesh reinforcement "ladders". The same applies for in-situ-cast and compacted soil wall constructions. Also here the contact between soil and wire-mesh is intense.

When walls are masoned with clay-soil between the stones, the stones need to fit tightly together to hold the wire-mesh knots in place.

In case the walls are constructed with cement blocks or cement stabilised earth blocks, these are usually built with cement mortar as the cement and sand aggregates are available to make the blocks. Cement block walls (8"-10") are made smaller than the two-stone walls (18"). Because they are thinner, the distance between the two wires of the "ladders" will be 7" to 9" respectively and the internal moment arm shorter. On the other hand, the cement block wall is substantially lighter than the 18" two-stone wall and thus will require about the same amount of reinforcement; one "ladder" in alternating courses.

The following calculations are based on the two-stone 18" wall construction.

[7] Detailed earthquake registration demonstrates that between 1960 and 1999 more than 300 minor earthquakes have taken place with a magnitude between 5 and 6 on the Richter Scale. With increased population and more durable buildings, the risk of a construction being affected during its lifetime by a large earthquake has increased four-fold as compared to the last century.

Bearing Walls are to be Pointed with Light Cement Mortar on Both Faces

The recommendations indicated below are based on the pointing of the outer faces of the masonry wall construction with cement mortar (10:1).

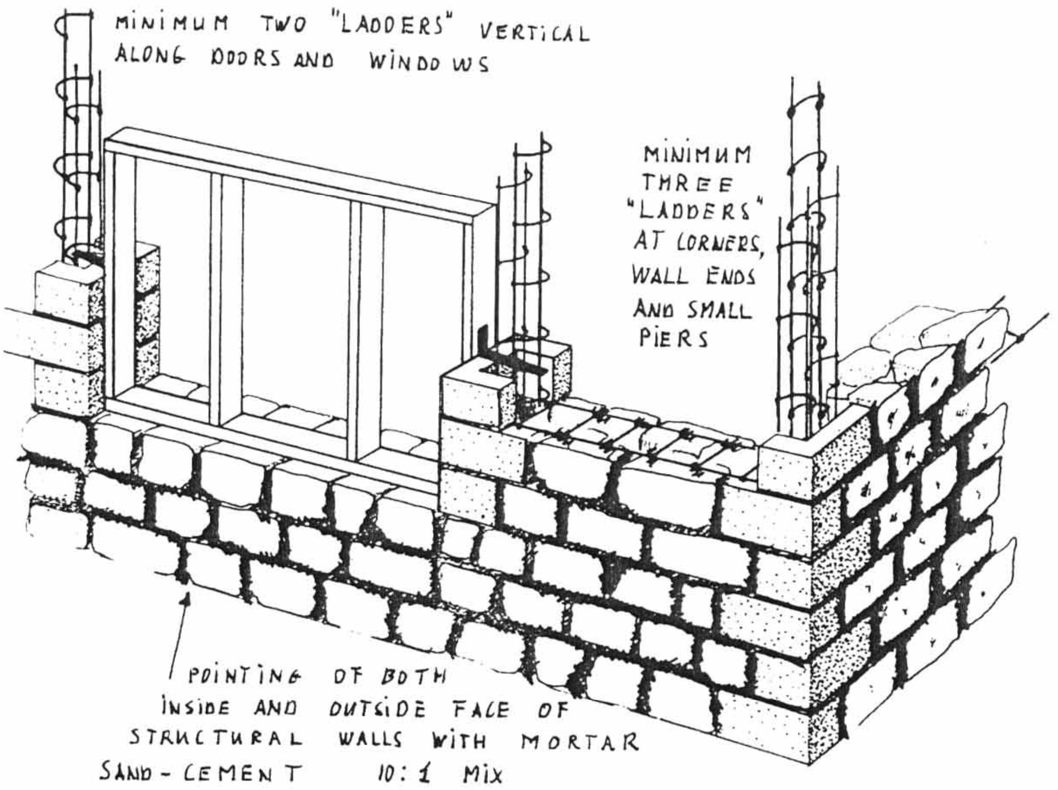

FIGURE 15. DETAILS OF "LADDERS" IN WALL SECTION WITH WINDOW AND NORMAL PIER

Strength of the Hot-Dip Galvanised Wire

The length wires of the "ladders" (parallel wires with cross-wires at one-foot intervals) are made of 2.3mm diameter hot-dip galvanised wire. The tensile strength of these wires in the elastic zone is 60,000 psi or 50 kg/mm^2.

The 2.3mm wire has a cross-section of 4.15mm^2, or more than 200 kgf tensile strength with a breaking strength of 400 kgf. A double wire "ladder" can therefore easily develop tensile resistance of 400 kgf (with breaking at 800 kgf)[8].

The cross-wires of the "ladders" are made of 2mm wire, having a cross-section of about 3mm^2. This thickness has been chosen as the cross-ties can be easily made with this diameter.

Estimated Horizontal Earthquake Forces

Earthquake forces in the Northern Areas[9] are considered to be moderate. Most dwellings are built on solid ground with a large number of subsurface rock and boulders. In general terms these conditions result in maximum horizontal forces (due to ground accelerations) of about 10-15%. For buildings that are required to remain intact after a large earthquake, a horizontal force of 15% is considered.

Perpendicular Forces to the Wall

[8] For calculation purposes, only the tensile strength in the elastic range has been considered, not the theoretical breaking strength.

[9] The highest earthquake incidence is found in Chitral. However, the entire Northern Areas is considered as having the same risk of large earthquakes, but with less occurrences per century.