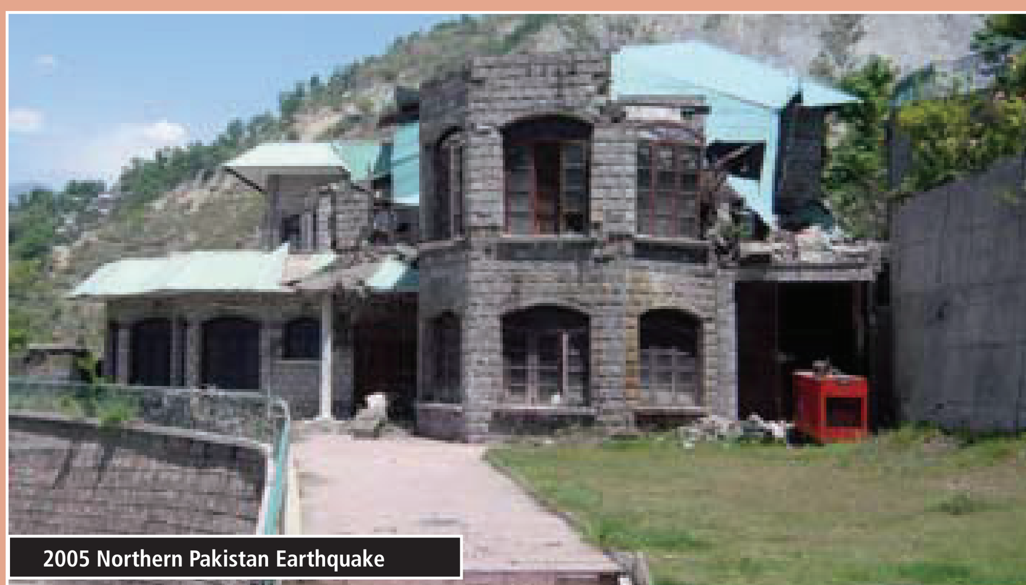
4.3 Typical Strengths of Masonry

The crushing strength of masonry walls depends on many factors such as the following:

1) Crushing strength of the masonry unit.
2) Mix of the mortar used and age at which tested. The mortar used for different walls varies in quality as well as strength. It is generally described on the basis of the main binding material such as cement or lime mortar, cement lime composite mortar, lime-pozzolana or hydraulic lime mortar. Clay mud mortar is also used in many countries, particular in rural areas.
3) Slenderness ratio of the wall. That is, the lesser of the ratio of effective height and effective length of the wall to its thickness. The larger the slenderness ratio, the smaller the strength.

Figure 4.6: **Damaged unreinforced masonry house (Muzafarabad, Pakistan)**



4) Eccentricity of the vertical load on the wall. The larger the eccentricity, the smaller the strength.
5) Percentage of openings in the wall. The larger the openings, the smaller the strength. The tensile and shearing strengths of masonry mainly depend upon the bond or adhesion at the contact surface between the masonry unit and the mortar and, in general, their values are only a small percentage of the crushing

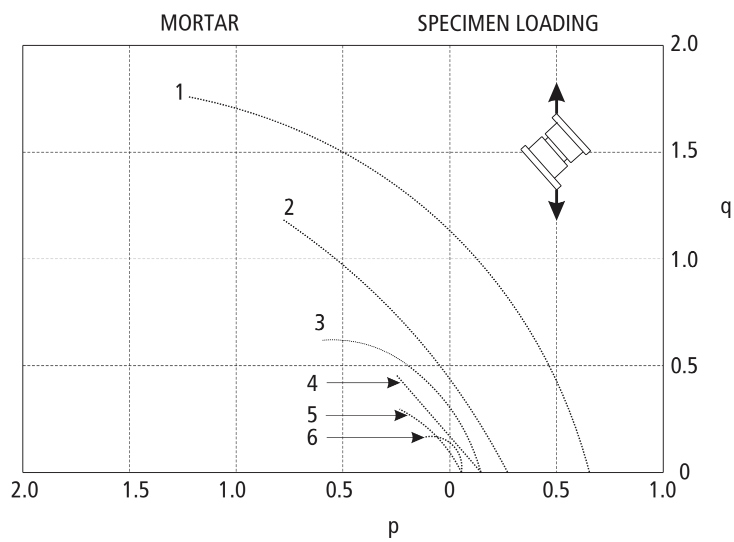
strength. A mortar richer in cement or lime content, the higher is the percentage of tensile and shearing strength in relation to the crushing strength. Tests carried out on brick-couplets using hand-made bricks in cement mortar give the typical values as shown in Table 4.1. (The values in Tables 4.1, 4.2 and 4.3 may be used as default values where more precise values are not available or nationally spacified values are not available.)

Table 4.1: Typical strengths of masonry

Mortar mix		Tensile strength (MPa)*	Shearing strength (MPa)*	Compressive strength (MPa)* corresponding to crushing strength of masonry unit			
Cement	Sand			3.5	7.0	10.5	14.0
1	12	0.04	0.22	1.5	2.4	3.3	3.9
1	6	0.25	0.39	2.1	3.3	5.1	6.0
1	3	0.71	1.04	2.4	4.2	6.3	7.5

* 1 MPa = 1N/mm^2 ≈ 10 kgf/cm^2

Figure 4.7: Combined stress couplet test results



p: Normal stress (MPa)*
q: Shear stress (MPa)*
* 1 MPa = 1N/mm^2 ≈ 10 kgf/cm^2

Mortars

1: "1 : 3" Cement-sand
2: "1 : 5" Cement-sand
3: "1 : 2" Lime-crushed brick powder (surkhi)
4: "1 : 2" Lime-cinder
5: "1 : 12" Cement-sand
6: Clay mud

Brick couplet tests under combined tension-shear and compression-shear stresses show that the shearing strength decreases when acting with tension and increases when acting with compression. Fig. 4.7 shows the combined strengths.

The tensile strength of masonry is not generally relied upon for design purposes under normal loads and the area subjected to tension is assumed cracked. Under seismic conditions, it is recommended that the permissible tensile and shear stresses on the area of horizontal mortar bed joint in masonry may be adopted as given in Table 4.2.

Table 4.2: Typical permissible stresses

Mortar mix or equivalent			Permissible stresses		Compressive strength (MPa)* of unit			
Cement	Lime	Sand	Tension (MPa)*	Shear (MPa)*	3.5	7.0	10.5	14.0
1	–	6	0.05	0.08	0.35	0.55	0.85	1.00
1	1	6	0.13	0.20	0.35	0.70	1.00	1.10
1	–	3	0.13	0.20	0.35	0.70	1.05	1.25

* 1 MPa = 1N/mm^2 ≈ 10 kgf/cm^2

The modulus of elasticity of masonry depends upon the density and stiffness of the masonry units, besides the mortar mix. For brickwork, the values are of the order 2 000 MPa for cementsand mortar in "1 : 6" proportion. The mass density of masonry mainly depends on the type of masonry unit. For example brickwork has a mass density of about 1 900 kg/m^3 and dressed stone masonry 2 400 kg/m^3.

The slenderness ratio of the wall is taken as the lesser of h/t and ℓ/t where h = effective height of the wall, ℓ = its effective length and t = its thickness. The allowable stresses in Table 4.2 must be modified for eccentricity of vertical loading due to its position and seismic moment and the slenderness ratio multiplying factors given in Table 4.3. The effective height h may be taken as a factor times the actual height of wall between floors, the factor being 0.75 when floors are rigid diaphragms and 1.00 for flexible roofs; it is 2.0 for parapets.

The effective length ℓ will be a fraction of actual length between lateral supports, the factor being 0.8 for wall continuous with cross walls or buttresses at both ends, 1.0 for continuous at one end and supported on the other and 1.5 for continuous at one and free at the other.

Table 4.3: Stress factor for slenderness ratio and eccentricity of loading

Slenderness ratio	Stress factor k for eccentricity ratio *e/t*						
	0	0.04	0.10	0.20	0.30	0.33	0.50
6	1.000	1.000	1.000	0.996	0.984	0.980	0.970
8	0.920	0.920	0.920	0.916	0.880	0.870	0.850
10	0.840	0.835	0.830	0.810	0.770	0.760	0.730
12	0.760	0.750	0.740	0.705	0.664	0.650	0.600
14	0.670	0.660	0.640	0.604	0.556	0.540	0.480
16	0.580	0.565	0.545	0.500	0.440	0.420	0.350
18	0.500	0.480	0.450	0.396	0.324	0.300	0.230
21	0.470	0.448	0.420	0.354	0.276	0.250	0.170
24	0.440	0.415	0.380	0.310	0.220	0.190	0.110

(i) Linear-interpolation may be used. (ii) Values for $e/t = 0.5$ are for interpolation only.

4.4 General Construction Aspects

4.4.1 Mortar

Since tensile and shear strength are important properties for seismic resistance of masonry walls, use of mud or very lean mortars is unsuitable. A mortar mix "cement : sand" equal to "1 : 6" by volume or equivalent in strength should be the minimum. Appropriate mixes for various categories of construction are recommended in Table 4.4. Use of a rich mortar in narrow piers between openings is desirable even if a lean mix is used for walls in general.

Table 4.4: Recommended mortar mixes

Category*	Proportion of cement-sand or cement-lime-sand**	
	Cement-sand	Cement-lime-sand
I	"1 : 4" or richer	"1 : ½ : 4½" or richer
II	"1 : 5" or richer	"1 : 1 : 6" or richer
III	"1 : 6" or richer	"1 : 2 : 9" or richer
IV	"1 : 7" or richer	"1 : 3 : 12" or richer

* Category of construction is defined in Table 3.3.
** In this case some pozzolanic material like Trass (Indonesia) and Surkhi (burnt brick fine powder in India) may be used with lime as per local practice.