Chapter Three

Strengthening Stone Masonry Buildings

3.1 Levels of Technology

A programme to encourage stronger housing construction should be aimed at both the builder, who constructs the building, and the house owner, who pays for the building. Those who build houses in the villages have been categorised into 'owner builders', 'craftsman builders' and 'contractor builders'. The nature of strengthening measures proposed and the structure of a programme to encourage their use would have to be significantly different for each type of builder being addressed. Table 3.1 classifies possible levels of improvement to construction practices, based on the degree of building skills and equipment needed and the scale of operation involved.

APPROPRIATE LEVELS OF IMPROVEMENT TO BUILDING CONSTRUCTION

A. Owner builder, no cash cost, better use of local materials, only domestic tools needed, simple to apply.

B. Owner or craftsman builder, minimal cash cost, use of better selected or greater quantities of local materials, building tools needed, some traditional building skills needed.

C. Owner or craftsman builder, some cash cost, use of purchased building materials able to be transported by cart, masonry and carpentry skills needed.

D. Craftsman construction, moderate cash cost, use of purchased building materials needing transport by lorry, concrete or cement mixing skills needed.

E. Contractor construction, high cash cost, extensive use of purchased building materials, plant and equipment needed, training required.

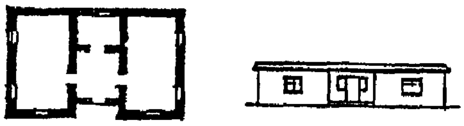
Table 3.1

The most important aspect of advocating measures to strengthen buildings is, however, the cost of doing so. Some houseowners may be able and willing to spend more on building strengthening than others. Houses in Eastern Anatolia, like houses anywhere, are built for a wide range of costs. Figure 3.1 illustrates different grades of house currently found under construction in the villages, with their approximate costs.

The costs of building a traditional house can be broken down into 'local materials (freely available if collected)', 'labour', and 'cash cost'. In village construction cash is usually the rarest resource. It is in this context of a wide range of construction abilities and resources available that proposals for reducing vulnerability should be considered. At one level there should be the possibility of building a house stronger for someone with no extra cash available. There should also be options for strengthening houses for those who wish to do so and can afford different levels of cost.

3.2 Low-Cost and No-Cost Improvements

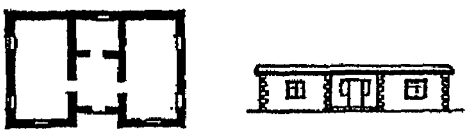
In the progression of building damage to stone masonry buildings in an earthquake outlined above, the first element to fail is the weakest part of the structure. Often a defect in the construction of a building causes one element to be significantly weaker than others and for it to begin the process of failure. Once failure has begun, the progression of damage is relatively rapid. One method of reducing damage is to reduce the defects which assist its progression. Table 3.2 provides a list of



A Basic House, Traditional

Built by owner and his family.
Random rubble masonry in soil mortar with flat soil roof.
% of new construction in all villages that could be classified as 'basic house, traditional', (estimated from field studies): 25%
Typical costs of 13 x 9m house (78 m^2 internal floor area):

Local Materials*	Market Materials, cash cost* (TL 1983)		Labour	Total Cash Cost* (TL 1983)
rubble: 75 m^3 (150 tonnes)	Structure only:	160 000	80 man days	
soil: 75 m^3	Non-structural fixtures and fittings (windows, doors, electrical etc.):	160 000		
water: 4 000 litres				
+ brushwood, branches for roof.				
	Total.	300 000		300 000



B Medium Quality, Traditional Craftsman-Built

Built by Craftsman Builder with unskilled labour from householder's family.
Random rubble masonry with dressed stone corner quoins, soil mortar, flat soil roof.
% of new construction in all villages classified as 'medium-quality traditional, craftsman-built', (estimated from field studies): 50%
Typical costs of 13 x 9m house (78 m^2 internal floor area):

Local Materials*	Market Materials, cash cost* (TL 1983)		Labour	Total Cash Cost* (TL 1983)
rubble: 70 m^3 (140 tonnes)	Structure only (roof joists, boarding):	180 000	30 days unskilled (provided by householders family)	
dressed stones: 90	Non-Structural (windows, doors, ironmongery etc.).	200 000	50 days skilled, Craftsman @ 3 000 TL pr day = 150 000 TL	
soil: 75 m^3				
water: 4 000 litres				
	Total:	380 000		530 000

C Modernised Traditional

Built by Craftsman Builder and his assistants.
Loadbearing masonry (stone, rubble, brick, or concrete block), stone plinth, with pitched roof on timber trusses.
% of new construction in all villages classified as 'modernised traditional', (estimated): 25%
Typical costs of 13 x 9m house, concrete block walls (100 m^2 internal floor area):

Local Materials*	Market Materials, cash cost* (TL 1983)		Labour	Total Cash Cost* (TL 1983).
rubble: 25 m^3 (50 tonnes)	Structure only (concrete blocks, mortar, roof):	500 000	60 days by craftsman with his assistants, @ 4 000 TL pr day = 240 000 TL	
water: 1 000 litres	Non-structural (finishes, joinery, services, fixtures, fittings):	500 000		
	Total:	1 000 000		1 240 000

D Reinforced Concrete Frame House,

Built by Contractor-Builder.
Concrete frame with hollow-brick or block infill, concrete foundations, pitched roof on timber trusses, concrete floor slabs.
% of new construction in all villages built in reinforced concrete (estimated): 0.5%
Typical costs of 13 x 9m house, two-storey (single storey r.c. is uncommon), 200 m^2:

Local Materials*	Market Materials, cash cost* (TL 1983)		Labour	Total Cash Cost* (TL 1983)
water: 10 000 litres	Structure only (frame, foundations, roof, infill walls, external render):	1 500 000	100 man days by contractor team @ 5 000 TL pr man-day = 500 000 TL	
	Non-structural (internal finishes, joinery, fixtures, fittings,):	2 000 000		
		3 500 000		4 000 000

* Materials costs do not include transport of materials to site.

Figure 3.1 Qualities, Materials and Construction Costs of Typical Village Houses examples of building measures that could be taken using only local building materials and traditional skills, i.e. levels of building improvement types A and B.

EXAMPLES OF LOW-COST AND NO-COST MEASURES
TO REDUCE EARTHQUAKE VULNERABILITY IN TRADITIONAL CONSTRUCTION

	Level of Improvement
A. Preventative Construction and Good Building Practice	
1. Prevention of water penetration through roof:	
Grading of soil by using soil from a deeper pit (i.e. excluding topsoil)	A
Grading soil by seiving and adding clay.	A
Extensive compaction of soil on roof, rolling in thin layers.	A
Use of soil stabilisers e.g. car sump oil.	A
cement or lime.	C
Construction of uniform gradients on roof with drainage paths.	A
Construction of eaves overhang with drainage spouts.	B
Paving roof with flat stones	B
Internal drainage in soil roof	B
Non-permeable membrane in roof	B
2. Construction of large foundations, deep and wide.	B
3. Improvement of surface water drainage away from building.	A
4. Improvements to wall construction:	
Stones laid with stable centre of gravity and in good contact with at least two other stones.	A
Selection of long flat stones ('blocks') for use in wall construction	B
Care taken to stagger jointing between courses	A
Use of 'through stones' between skins of masonry	B
'Dog-toothing' stones of each skin together.	A
Use of dressed stone for corner construction	B
Keying of internal walls into external walls	A
External render applied to all walls	B
5. Improvements to the use of structural timber:	
Limitation of span : depth ratio of beam	A
Even distribution of loads onto beams.	A
Beams to be supported on wall plates	B
Fixings between beams and wall plates	B
Fixings between beams and cross members of roof	B
Beams prevented from contact with soil by end plate	B
Beam ends ventilated by provision of air gap	A
Use of timber treated with preservative	B
B. Annual Maintenance to Reduce Deterioration and Weakening	
1. Roof stripped and top soil level of roof recompacted before each winter. Gradients and drainage paths reconstructed	A
2. Walls repointed or sections of masonry rebuilt where cracks have developed, mortar has been dislodged, or bulges and leaning can be detected.	A
3. Replacement of rotten or infested timbers	B
4. Reconstruction of site drainage	A
C. Reinforcement Measures in Local Materials (excluding additional timber)	
1. External buttresses at corners of masonry walls and at intervals along long walls, preferrably out of dressed stone	B
2. Dressed stone corners extending two or three stones' length into each wall	B
3. Horizontal double courses of dressed stone masonry at intervals up wall height, e.g. ground, cill, lintol and eaves level	B
4. Long bearings on roof beams and lintols	A
5. Duplication or triplication of fixings (nails, straps etc.,) between timber members	B

Table 3.2

3.3 Reinforcing Stone Masonry Construction

Other methods for making buildings stronger need to be evaluated against their cost. The range of potential earthquake-resistant construction is only limited by cost. Strengthening measures appropriate to rural buildings in Eastern Anatolia need to be comparable with other construction costs, and a target range of 5% to 50% of the construction costs in figure 3.1 are aimed for in defining appropriate strengthening proposals. In figure 3.2 the most effective strengthening strategy for the money available at different levels of cost and for different levels of building skills is presented. Costs are calculated for the standard house in figure 3.1, for approximate additional cost of materials based on the costings obtained from construction experiments described in Chapter Four.[1]

A number of earthquake codes and manuals for low income buildings include recommendations about the structural form, particularly the symmetry of the plan shape, positioning of openings, type of roof etc. In general however it must be assumed that the planning and form of a building, which is the result of many needs, traditions and personal preferences, is much less likely to be influenced by earthquake considerations than the detailed construction of the house. There is some argument for trying to persuade owners starting out on a new house to build a smaller house built to a higher quality for the money he has available. But the main concern of a programme to reduce earthquake damage should be the construction of the structure of whatever the owner is intending to build.

Resisting Separation of Walls

The most common form of failure of rubble masonry buildings is the separation of walls at the corners. This directly contributes to the collapse of a building by freeing walls which then disintegrate. The most important single element to restrain the progression of damage is any device which ties one wall more firmly to another. Concrete ringbeams are often recommended,[2] but the thinnest concrete beam would require around 2.5 cubic metres of concrete and over 120 metres of 12 mm steel bars, costing around 50 000 TL (1983). The scale of operation, cost and skill involved effectively rules out its use on an owner-built traditional house. It may be appropriate for craftsman-built houses if the craftsman is proficient in concrete construction. Some bonding between walls may be achieved by bedding lengths of steel in the masonry at corners, or wire mesh horizontally across construction joints, or by the use of timber as a horizontal ringbeam in place of concrete. The use of the horizontal timber *hatıl* in stone masonry construction has the advantage of already being a familiar part of village buildings (although it may be regarded as old fashioned). The cost of a single hatıl, around 25 000 TL (1983), is about half that of a thin concrete ringbeam. The bonding of a timber hatıl to a stone masonry wall is mainly through the compression of the weight of masonry above it. For this reason the most effective level for a single hatıl is not at the top of the wall where there is no load on it, but at lintol level. Traditionally at least three hatıls were used. This tripling of the reinforcement in the wall gives a much better chance of resisting failure, but the cost of three hatıls may be more appropriate to a craftsman-built house than to basic qualities of construction.

Prevention of Roof Collapse

An important consideration is the use of the roof to strengthen the walls which support it.[3] A monolithic roof tied to all four walls not only ties the walls together and braces them to prevent wall separation, but also resists roof collapse until large proportions of the supporting walls have disintegrated. The best example of a diaphragm is a reinforced concrete slab, bearing onto all four walls.[4] This is a complex and expensive structural element to construct involving shuttering spanning the entire building and the making of a steel reinforcing mesh and it is probably only appropriate for contractor construction. Flat soil roofs could also be made monolithic fairly easily by timber cross members fixed between the beams, or boarding nailed across them, or by the use of a sheet material, like plywood, nailed to every beam. The very minimum that could be done to prevent local roof collapse is a sturdy wall plate to which all roof beams are nailed, on both of the supporting

1 Coburn and Spence (1984).

2 Arya et al. (1980), Daldy (1972).

3 United Nations (1975).

4 Earthquake Research Institute (1973) and (1975).

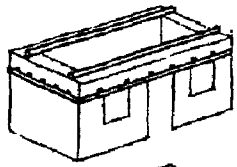
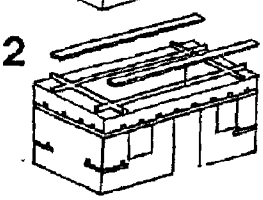
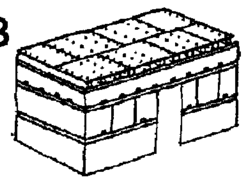
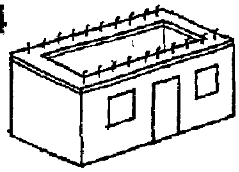
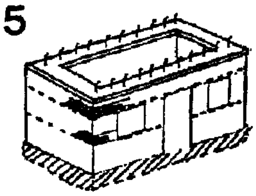
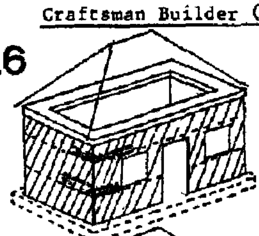
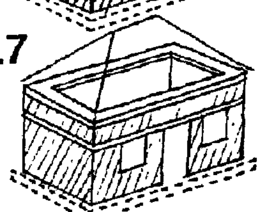
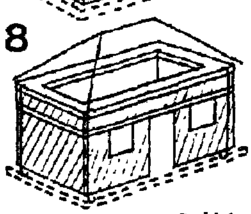
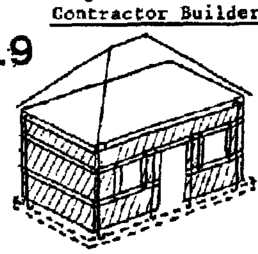
Level of building operation required:			Owner Builder or Craftsman Builder	Approximate Additional Cash Cost (materials only) (TL 1983)	As % cost of House Type: A	B	C
C	L1		● Single horizontal timber hatil at lintol level. ● Sturdy wall-plate 10 x 10 cm, running length of loadbearing wall with all roof beams nailed securely to wall plate. ● All good building practices and annual maintenance from table 2, (A).	30 000	10%	6%	-
C	L2		● Single horizontal timber hatil at lintol level. ● Sturdy wall-plate with tie across non-loadbearing wall. ● Timber corner reinforcements at cill level. ● Planks nailed across roof beams. ● Good building practices and annual maintenance from table 2, (A).	45 000	15%	9%	-
C	L3		● Three horizontal hatils; eaves, lintol cill levels. ● Plywood sheeting or boarding nailed across roof beams. ● Good building practices and annual maintenance from table 2, (A and B).	120 000	40%	23%	-
			Craftsman Builder only				
D	L4		● Thin reinforced concrete ringbeam (10 cm x 60 cm, 2 ϕ 12 bars with ϕ6 bars @ 40 cc) ● Steel straps cast into ringbeam for fixing roof beams or trusses. ● Good building practices and maintenance from table 2, (A and B).	50 000	-	9%	4%
D	L5		● Thin reinforced concrete ringbeam ● Two horizontal courses of light reinforcement (2 o10 bars or expanded metal mesh) laid in thin courses of cement mortar. ● Foundations of large boulders in cement mortar. ● Plywood sheeting or boarding nailed over roof. ● Good building practices, table 2, (A and B).	150 000	-	28%	12%
			Craftsman Builder (or Contractor Builder)				
D	L6		● Substantial reinforced concrete ringbeam, (20 x 60cm, 4 ϕ12 bars with ϕ6 stirrups @ 30cm) ● 1:6 cement:sand mortar throughout. ● Two horizontal courses of light reinforcement. ● Reinforced concrete foundations. (Table 2 measures less critical) (Lightweight pitched roof assumed)	270 000	-	51%	22%
D	L7		TURKISH BUILDING CODE SPECIFICATION (ERI 1975) ● Substantial reinforced concrete ringbeam. ● 1:2:6 cement:lime:sand mortar throughout ● Reinforced concrete lintol beam, as ringbeam. ● Reinforced concrete foundations.	350 000	-	66%	28%
D	L8		● Substantial reinforced concrete ringbeam. ● Reinforced concrete lintol beam. ● Vertical reinforcement, in concrete at corners. (ϕ16 bar anchored to foundations and ringbeam in 10 cm cavity filled with concrete). ● Reinforced concrete foundations. ● 1:2:6 cement:lime:sand mortar.	400 000	-	-	32%
			Contractor Builder only				
E	L9		● Reinforced concrete roof slab cast monolithically with substantial reinforced concrete ringbeam. ● Two horizontal reinforced concrete wall beams, as ringbeam, at lintol and cill levels. ● Vertical reinforcement at corners, full height. ● Vertical reinforcement at edges of openings between cill and lintol beams. ● Reinforced concrete foundations ● 1:2:6 cement:lime:sand mortar	500 000	-	-	40%

Figure 3.2 Levels of Reinforcement of Stone Masonry Houses

walls. It should be strong enough to span a minor collapse of masonry beneath it.

Strengthening Walls

The use of reinforced concrete to make a strong ringbeam is inappropriate if the walls are so weak that they disintegrate underneath it. Walls need a minimum level of strength and integrity before they behave as structural units which are worth reinforcing. There should be balance between the distribution of strengthening throughout the structure. Better quality wall construction involves more use of square stones in key positions, better quality mortars, and horizontal courses of reinforcement. Better quality mortars, like cement-sand mortars not only have some tensile strength that can bond stones together, they are impervious to the water penetration which severely weakens walls in soil mortar. Unfortunately the volume of mortar used in the construction of a rubble masonry wall is considerable. For example, the external walls in figure 3.1 require around 40 cubic metres of mortar, which for a 1:6 cement-sand mortar would cost an extra 90 000 TL (1983). Weaker cement-sand mixes than 1:6 would be cheaper but become highly variable in strength, difficult to mix effectively and not worth their expense. Instead of trying to replace the soil mortar, a more cost-effective way of improving the integrity of a rubble masonry wall is to use horizontal courses of greater strength interspersed with the normal weak masonry. The use of timber hatıls has already been discussed. Steel bars or expanded metal mesh laid in a thin course of cement mortar at intervals up the height of the wall would be an appropriate intermediate level of horizontal strengthening for stone masonry walls in soil mortar which would give them sufficient integrity to justify other reinforcement.

Vertical Reinforcement

Vertical reinforcement is strongly advocated by many manuals.[5] Vertical reinforcement is only really possible in buildings which have reinforced concrete foundations and a reinforced concrete ringbeam in which the ends of the vertical steel bar can be cast. In addition, the masonry must be capable of taking compression and acting in shear. Weak masonry walls would not justify vertical reinforcement and this is only appropriate as an additional measure for high-cost buildings.

3.4 Implementing Strengthening in the Villages

The technical achievement of greater levels of seismic resistance for rural structures within realistic cost limits seems feasible, providing that each proposal is carried out by the type of builder for which it is intended. It is envisaged that builders could be trained in these strengthening techniques and then encouraged to put them into practice, unsupervised, in their own village.

The will to incorporate strengthening in the construction of new houses depends on whether householders consider it important to do so. Interviews with villagers show that the fear of a severe earthquake is often genuine but the chances of being struck by one are felt to be remote. This is perhaps not surprising when, for any particular village the return period for a damaging earthquake is usually longer than a man's lifetime. It is probably accurate to say that awareness of earthquake risk is less than the actual risk, i.e. most people are probably more likely to be affected by an earthquake than they realise. An important part of any building strengthening programme should be a general education programme to make it clear to villagers in the most hazardous areas just how likely an earthquake is. There may also be villagers who are not aware of the potential for protecting themselves and are not aware that there are strengthening measures possible within their means. Everyone should be encouraged to protect themselves to the fullest extent possible.

However, inevitably one of the main reasons that most villagers do not already build more strongly is the cost involved in doing so. Villagers who are convinced of the need to build stronger buildings may simply be unable to afford to do so. For these people it may be necessary to consider subsidising the extra costs involved. The cost to the Government of Turkey of reconstructing earthquake damaged houses is considerable. There may be an economic justification for the government to become involved in subsidising strengthened house construction in village areas where it can be shown that by strengthening houses, the cost of future damage will be sufficiently reduced to justify it.

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5 Daldy (1972), Arya et al. (1980).