Chapter Two

Buildings and Earthquake Vulnerability in Eastern Anatolia

2.1 Traditional Village Houses

The traditional buildings of most concern for the reduction of earthquake losses in the rural areas are relatively homogeneous in structural and construction type. They are loadbearing wall structures, predominantly stone masonry of one sort or another, nearly all single storey, with a flat soil roof on timber beams, figure 2.1. These houses are massively built with wall thicknesses of over 60 cm and soil 20-50 cm deep compacted on the roof. The potential of these very massive structures to crush and suffocate the occupants if they collapse has been frequently observed, and the large mass of the roof is known to put high loads on the supporting structure during ground motion. The mass and low forms of these buildings are very well adapted to the climate of the region, with extreme seasonal fluctuations of temperature and harsh winters. The mass of the house is extremely important in providing a stable and comfortable thermal environment for its occupants, with low heating or cooling requirements. The environmental advantages of the massive construction generally outweigh possible earthquake dangers for the occupants.

The plans of the houses are relatively uniform, consisting of a collection of structural 'cells'- simple rectangular rooms- joined in fairly standard configurations. In figure 2.2(a) it can be seen that the basic form of a central hall with living rooms either side is found in a number of variations. The central entrance hall is an important focus of the house and varies considerably in its use and architectural expression. The dimensions of these rooms are quite consistent from building to building, as shown in figure 2.2(b).

The span of the rooms, controlled by the length of timber available for roof beams, is surprisingly consistent; over half of the rooms surveyed had a span of between 3.0 and 3.25 metres. The length of the structural unit is much less uniform but appears to fall into one of three categories; a short room, almost square in plan, used for cooking, ablutions or other small volume room; a standard room between 5 and 6 metres long, used for most living and sleeping areas; and a less common long room, up to 8.5 metres long, used for the prestigious salon rooms for sitting or formal meetings. The external height of these structures is also fairly standardised at between 2.5 and 3 metres from floor to eaves on flat ground.

The natural process of building is to construct the house in phases, adding rooms as the family needs and can afford them. The building stock consists of a collection of houses of different sizes and degrees of extension reflecting the sizes of households accommodated in each house, and their affluence. The average household size of the sample surveyed in Bingöl region was 8.5 people, with sometimes as many as 16 living in the same house. This compares with 5.7 persons per rural dwelling nationally.[1] The extended family is a distinct advantage in running the mixed and labour-intensive agricultural economy. The fact that houses and households are larger is significant in earthquake planning. The collapse of a single structure puts more people at risk.

Vibration tests carried out on a number of houses demonstrate that the structure is considerably stiffer in one direction, along the length of the room (10-15 Hz) than in the direction of the span (7-10 Hz). The structural system is one in which vibrations of greater amplitude and slower decay can be induced in the direction of the span than across it. Despite structural units sharing common bearing walls and being linked by a single massive earth roof, different vibration modes between the core of the house and later extensions can also be detected. In vibration the earth roof is itself flexible and does not act as a monolithic element nor unify the structural system below it.

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1 Unesco (1976) Country Monograph of Turkey

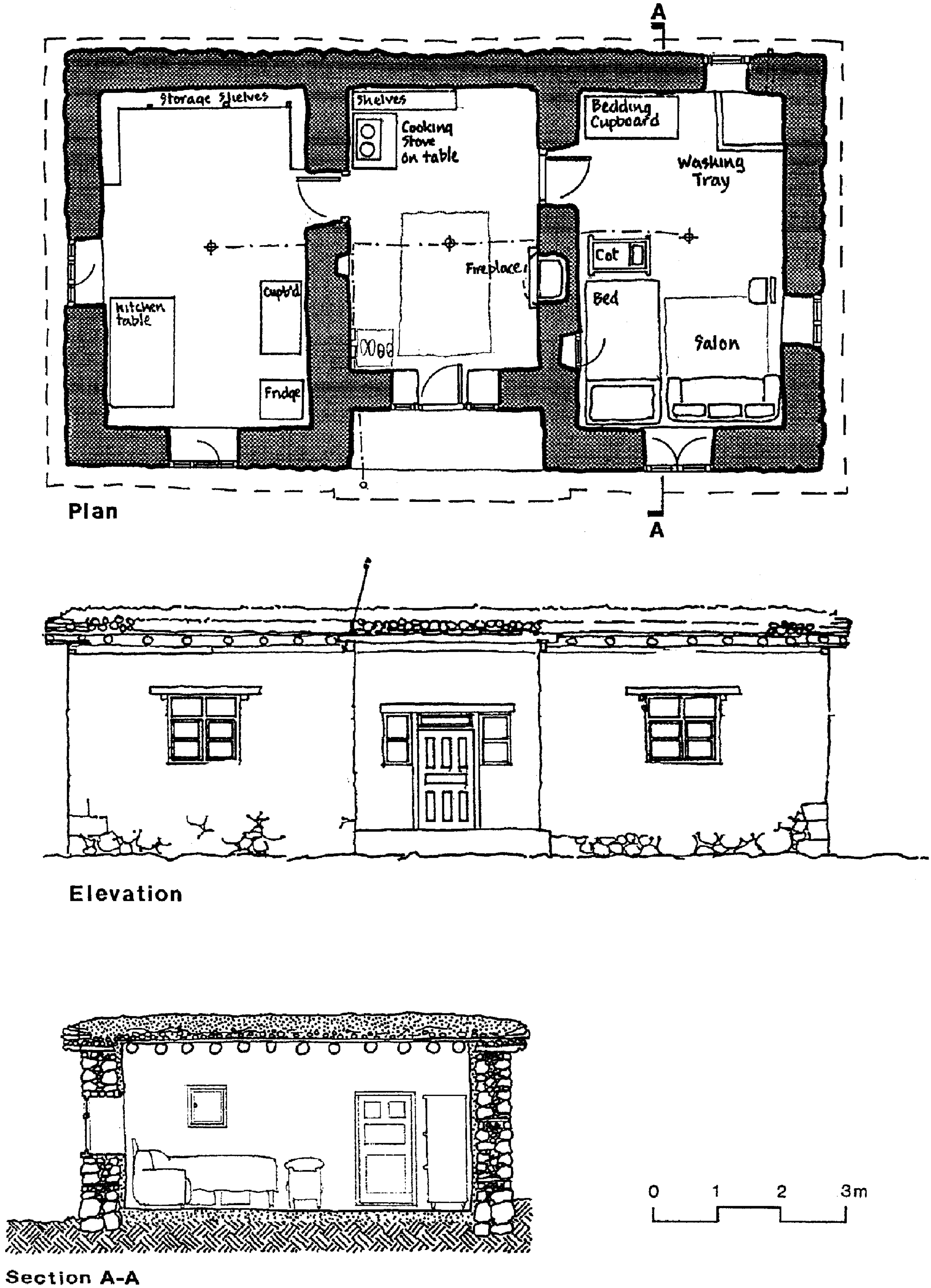


Figure 2.1 Traditional Stone Masonry House

2.2 Traditional Building Construction Methods

The main structural variable in the earthquake resistance of the building type of the region is in the quality of construction of the structural walls. A wide range of quality and type of stone masonry are used in the construction of otherwise very similar buildings. Walls are built almost everywhere from local stone. Regional geology plays a large part in the construction quality of the houses of the village.

Stone masonry is usually laid as two skins of stonework with an infill of rubble as a wall 60-80 cm thick. Different qualities of stone masonry can be roughly categorised as:

(a) *Poor quality masonry.* At its worst stone masonry consists of small, weathered stones used without cutting or shaping. They are piled on top of each other using thick mud mortar to hold them in position. This grade of masonry is commonly used for outhouse buildings and poorer houses. It is extremely vulnerable to ground tremors and to water penetration.

(b) *Common masonry.* Better qualities of masonry involve the shaping with hammers, or 'knapping' of larger stones to make angular blocks which are wedged together in courses. The mud mortar is used as a bedding and infill material after each course is laid. This is the most common type of masonry used in the houses but still has extremely low tensile strength and suffers from discontinuities where stones part from contact due to differential movement.

(c) *Dressed masonry.* The best quality uses large stones, often cut and shaped with chisels, or 'dressed', and laid as regular units in courses across each other with very little mortar in between. Having a relatively flat base and low centre of gravity, masonry from regular blocks is much more stable than random rubble. However, dressed stonework is an expensive and time-consuming method of building and depends on the availability of softer, easily worked stone. Often it is found only at the corners, around windows or as a facing veneer in houses and its main use is in the construction of prestigious buildings, such as mosques and minarets where structural integrity is crucial.

Other variations in construction quality include mortar quality (highly reliant on local soil type), use of external render, the degree of use of modern materials, and the use of horizontal reinforcement. In some of the older buildings, horizontal timber strengthening courses, or *hatıls* are found in the stone masonry. Generally placed at cill, lintol and eaves level, the hatıl ties the wall together, breaks up the vertical dimension of unsupported stonework and if continuous around the house adds a measure of ductility and structural integrity to the building. The use of hatıls was common in some areas of the study region until relatively recently when timber grown locally became progressively less available and market prices for timber rose. No examples have been seen of hatıls being put into new stone masonry construction although many of the older buildings have them.

2.3 Builders in the Village

In considering options for modification of traditional building methods or the introduction of new ones it is necessary to distinguish between 'owner builders', craftsmen builders' and 'contractor builders'. At one time all rural families knew basic building skills and most of the existing buildings were constructed by the male members of the family occupying them. Today owner-built houses are less common, perhaps 25% of all new construction; most construction is carried out by specialist craftsmen, some with separate trades of carpenter, mason etc. In such cases the owner decides on the layout and purchases the material for the builder to use. In the areas studied there appear to be one builder to between 50 and 100 households. In a few affluent villages, where modern construction using pitched timber truss roofs or reinforced concrete are found, contractor builders are emerging in order to employ the range of skills needed, hire labour and equipment, and organise on a larger scale. To date contractor builders account for only a small proportion of new construction in the villages, and are unlikely to constitute a major proportion of village construction for quite some time.

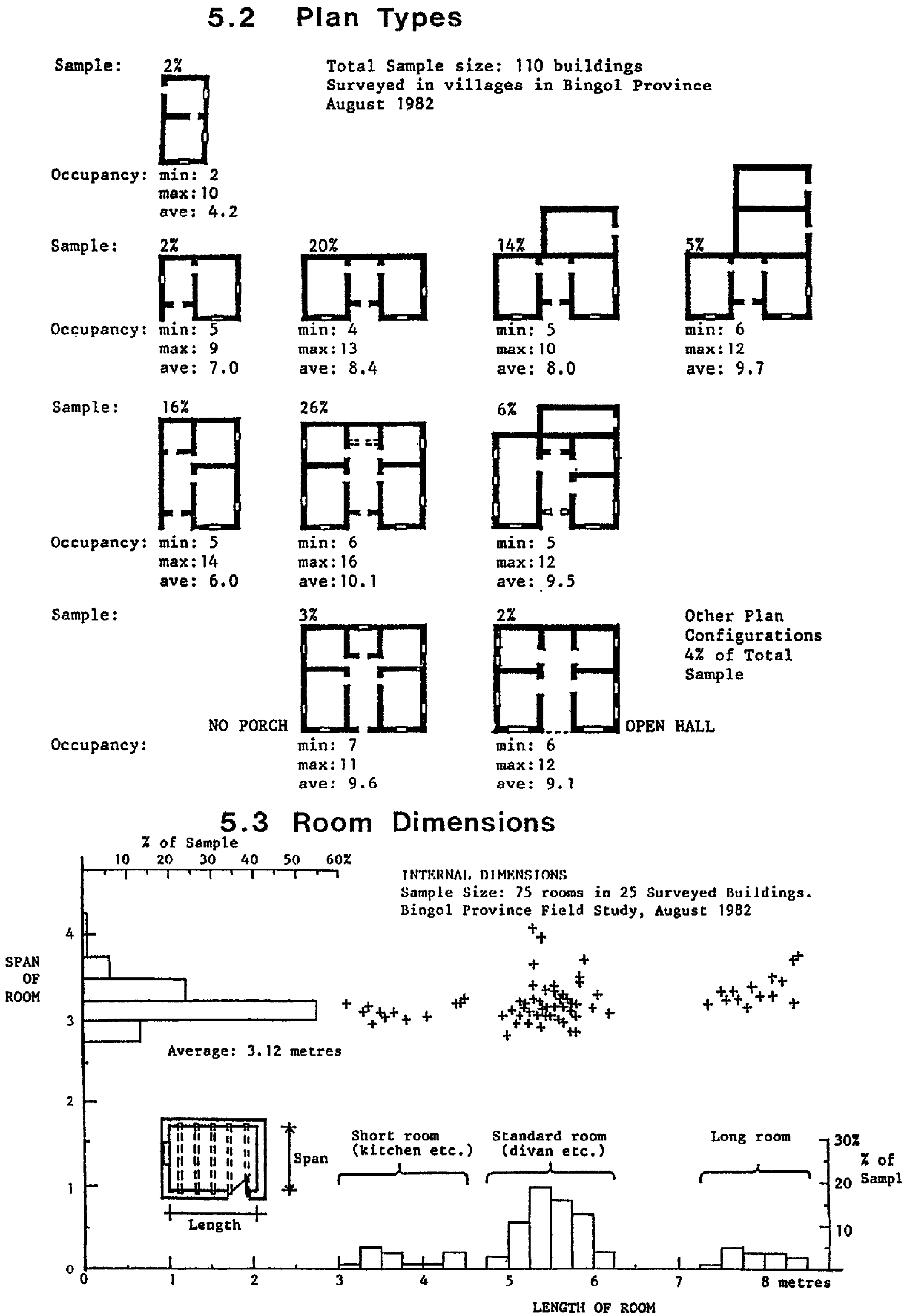


Figure 2.2 Plan Types of Traditional Buildings
a) Variations in plan types
b) Room dimensions of surveyed sample

2.4 Earthquake Field Studies

From studies of normal construction practices and typical building costs and from consideration of possible upgrading strategies it was concluded that the most effective and pragmatic approach to reducing earthquake vulnerability was to encourage village builders to improve the quality of the construction of stone masonry buildings. A more detailed analysis of the way buildings failed was needed in order to propose cost-effective modifications. This was obtained by conducting post-earthquake field investigations, both within the study area and elsewhere.

Earthquake damage to the stone masonry buildings typical of most of the study area was investigated in three post-earthquake field studies. In addition, earthquake damage to similar stone masonry construction with a very different structural form was investigated in the Yemen Arab Republic. The four earthquakes studied were:

1. The Erzurum-Kars earthquake of 30.10.1983. A two-man team joined the team from the Earthquake Research Department and Earthquake Engineering Research Center, arriving in the damaged area 4 days after the earthquake. 40 villages were visited, and 9 studied in greater detail, over a period of 9 days in the field.

2. The Şenkaya earthquakes of 18.9.1984 and 18.10.1984. The second of these earthquakes occurred while the study team was in the field for an investigation of damage from the first event, and a follow-up investigation of damage from the Erzurum-Kars earthquake a year earlier. This provided a rare opportunity to observe the effects of an earthquake as it was occurring. A total of 808 buildings in 8 villages were surveyed.

3. The Kösker earthquake of 23.4.1983. The damage in this small earthquake was limited to one village in Central Anatolia. A complete damage survey of this village was conducted, a total of 101 buildings.

4. The Dhamar earthquake in the Yemen Arab Republic of 13.12.1982. A two-man survey team carried out an independent survey of the whole damaged area. During 15 days in the field, 40 villages were visited, and a detailed damage survey of 250 buildings was carried out.

The objectives of each damage survey were to obtain data on the spatial distribution of damage, on the characteristics, both of siting and of building construction which contributed to the level of damage observed, and on the mechanism of damage and structural failure of typical buildings.

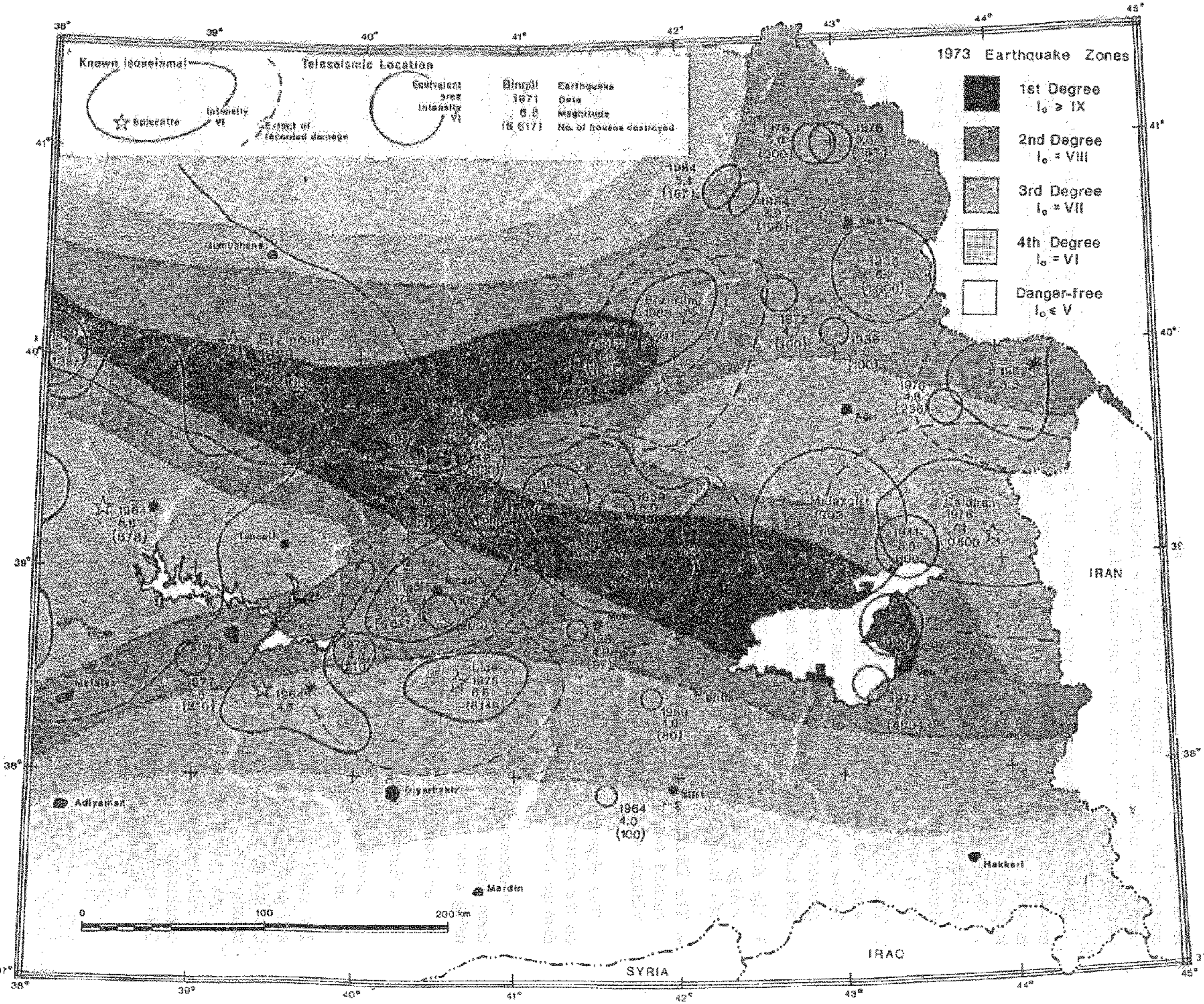
To obtain as much data as possible within the limitations of a short study and a small survey team under the difficult situation following an earthquake, a survey methodology was developed using a standard survey form. Where appropriate, the surveys were carried out at three levels

- an assessment of the total damage and its spatial distribution
- a significant sample of damaged buildings documented by rapid visual assessment of damage
- detailed investigations of a few typical buildings to determine methods of construction, defects and modes of failure

The rapid visual assessment included a description of the building, its size, shape, number of stories, and orientation; its materials, methods and quality of construction; the level of damage assessed on the six-point MSK scale of damage; and the location and mode of all observed damage. The standard survey form developed for this purpose is shown in figure 2.4.

Full reports on each of these field surveys were prepared.[2] In the following section the conclusions about the performance of stone masonry buildings in earthquakes deriving from all four field studies are presented.

[2] Coburn and Hughes (1983), Coburn and Hughes (1984), Coburn and Akkaş (1983), Coburn (1987).



ure 2 The ly A Earthquake Locations and Damage Distribution

2.5 Mechanism of Damage and Failure

Four general levels of severity of damage can be identified, as illustrated in figure 2.5:

(a) *Onset of damage*
- Principally non-structural damage and activation of latent weaknesses;
- Predominant in the fringe areas, in villages less than 5% heavily damaged;
- Damage is characterised by light or no damage to most buildings and heavy damage is suffered by weaker buildings.

(b) *Structural damage*
- Characterised by the separation of structural walls prior to collapse;
- Mainly found in the intermediate areas, in villages 5-40% heavily damaged;
- Wide variation in damage is found between neighbouring villages and between individual buildings.

(c) *Collapse*
- Progressive failure of structural walls bringing about the collapse of the roof;
- Most commonly found in the intermediate areas, in villages 40-75% heavily damaged;
- Wide variation in damage is found between neighbouring villages and between individual buildings.

(d) *Structural Disintegration*
- Sudden failure of all structural elements;
- Found within the epicentral areas of larger earthquakes and seen in villages suffering very heavy levels of destruction, 75-100% of houses heavily damaged or collapsed;
- Damage is characterised by total collapse and heavy damage with only moderate variation of damage between individual buildings.

At the end of an earthquake many buildings are left at different stages of damage and collapse. From the examination of the damage throughout the earthquake-affected area it is possible to observe types of damage indicative of different mechanisms of structural failure. These same mechanisms can be observed in a number of buildings and may be seen at different stages of advancement in buildings with increasing levels of damage. As each mechanism may be seen in many stages, from an undamaged building to fully collapsed, it can be deduced that the earthquake induces a continuous process of deterioration in any particular building and that some buildings have progressed further along this process than others. If the ground motion is considered as a sequence of loads applied to a structure then the deterioration of the building is the result of the degree of each loading together with the number of times the loading is applied. Once the strength of any structural element has been exceeded, the load required to continue and increase damage, i.e. the deformation, is considerably reduced and relative minor ground motions may cause damage to increase, for example aftershocks. Hence the onset of structural damage is a particularly important threshold for each building.

Wherever forces exceed the strength of the materials, failure will begin. It is most probable that this will occur in the areas of highest stress but with such variable construction materials, failure may begin first in areas of relatively low stress. In many cases the weakest element in a building derives from pre-existing decay or deformation of the structure and that is the point at which damage begins.

At very low levels of ground motion and in non-destructive dynamic testing of these structures, it can be seen that all the structure is set in motion and different parts of the structure attempt to vibrate with different characteristics. The stiff structural system of the loadbearing walls and roof and the flexible characteristics of the non-loadbearing walls vibrate in perpendicular directions and the corners of the walls, being the junction between them are the areas of highest stress. It is most probable that damage will begin and propagate through corner failure. Midwall damage does occur but it is relatively rare by comparison with corner damage. In figure 2.6 the progression of damage to the loadbearing stone masonry structural system is summarised. Different types of damage seen are shown as the result of a different sequence of failure of midwall or corner elements. For example the most common type of roof collapse seen, 'Roof collapse, two walls standing', is the

Turkish National Committee For Earthquake Engineering

ERZURUM Earthquake

Damage Survey

The Martin Centre for Architectural and Urban Studies

SURVEYOR :

PAGE :

VILLAGE :

DATE :

	BUILDING TYPE					WALLS										ROOF			
							LONG WALL					SHORT WALL							
	LOCATION	STRUCTURE FORM	USE	Nº OF STOREYS	Adjacent building	CONSTRUCTN TYPE	Approx Length (m)	Orientation N/S/E/W	Load-bearing? ✓-X	DAMAGE LEVEL	DAMAGE TYPE	Approx Length (m)	Load-bearing? ✓-X	DAMAGE LEVEL	DAMAGE TYPE	CONSTRUCTN TYPE	DAMAGE LEVEL	DAMAGE POSITN	NOTES
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WALLS - DAMAGE LEVEL	
0	No visible damage
1	Single cracks 0-5mm Bulges, leaning.
2	Single cracks 5-20mm Render dislodged Multiple cracks 0-5mm in 5 metres
3	Wall material dislodged Single cracks greater than 20mm Multiple cracks 5-20mm in 5 metres
4	More than half a wall collapsed or more than half a storey height
5	More than one wall collapsed

WALLS - DAMAGE TYPE

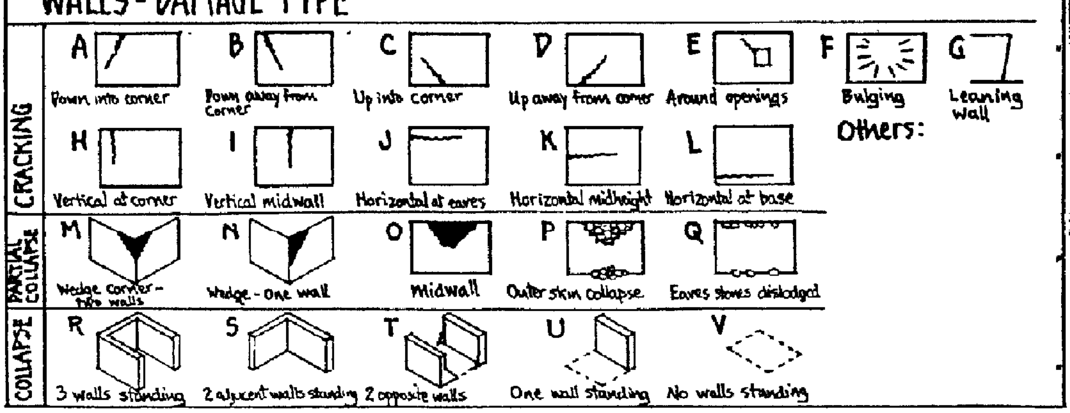

Figure 2.4 Earthquake Damage Survey Form

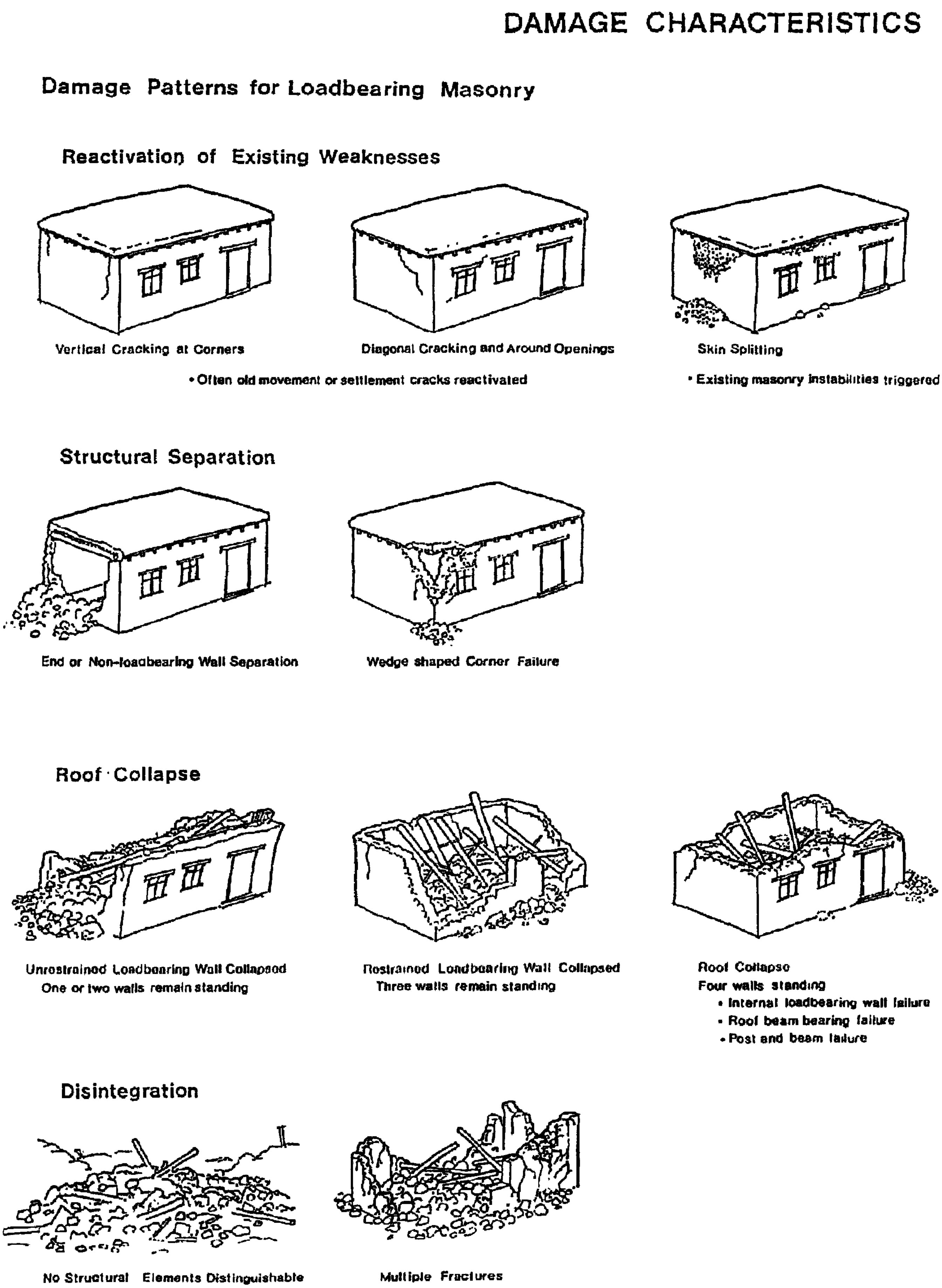

Figure 2.5 Damage Characteristics of Traditional Stone Masonry Buildings

result of the failure of three corners; first the two corners of a non-loadbearing wall, leading to the most common type of wall collapse, 'panel collapse of a non-loadbearing wall', followed by the failure of one of the remaining corners and the collapse of the unrestrained loadbearing wall. Similarly other damage types are the failure of other elements or a different order of failure and are less common. Sequences of failure and the relative frequency of occurrence of damage types suggest that the rules which govern damage progression are:

(1) Corners are more likely to fail than midwall elements.

(2) Any panel between two corner failures is unrestrained and is unlikely to remain standing.

(3) Non-loadbearing panels are more likely to fail than loadbearing.

(4) Elements generally fail one after another.

(5) The failure of one element increases the probability of failure of neighbouring elements.

These rules do not apply to the process of disintegration. There is some evidence to suggest that elements do not fail one after another but fail simultaneously, with the strength of all of the structure very quickly exceeded by the destructiveness of the ground motion. It is likely that this extreme vulnerability is due at least in part to a sizeable vertical component to the ground motion only experienced above the hypocentre. This destroys the structural integrity of the building by negating the gravitational forces essential to the bonding of traditional masonry.

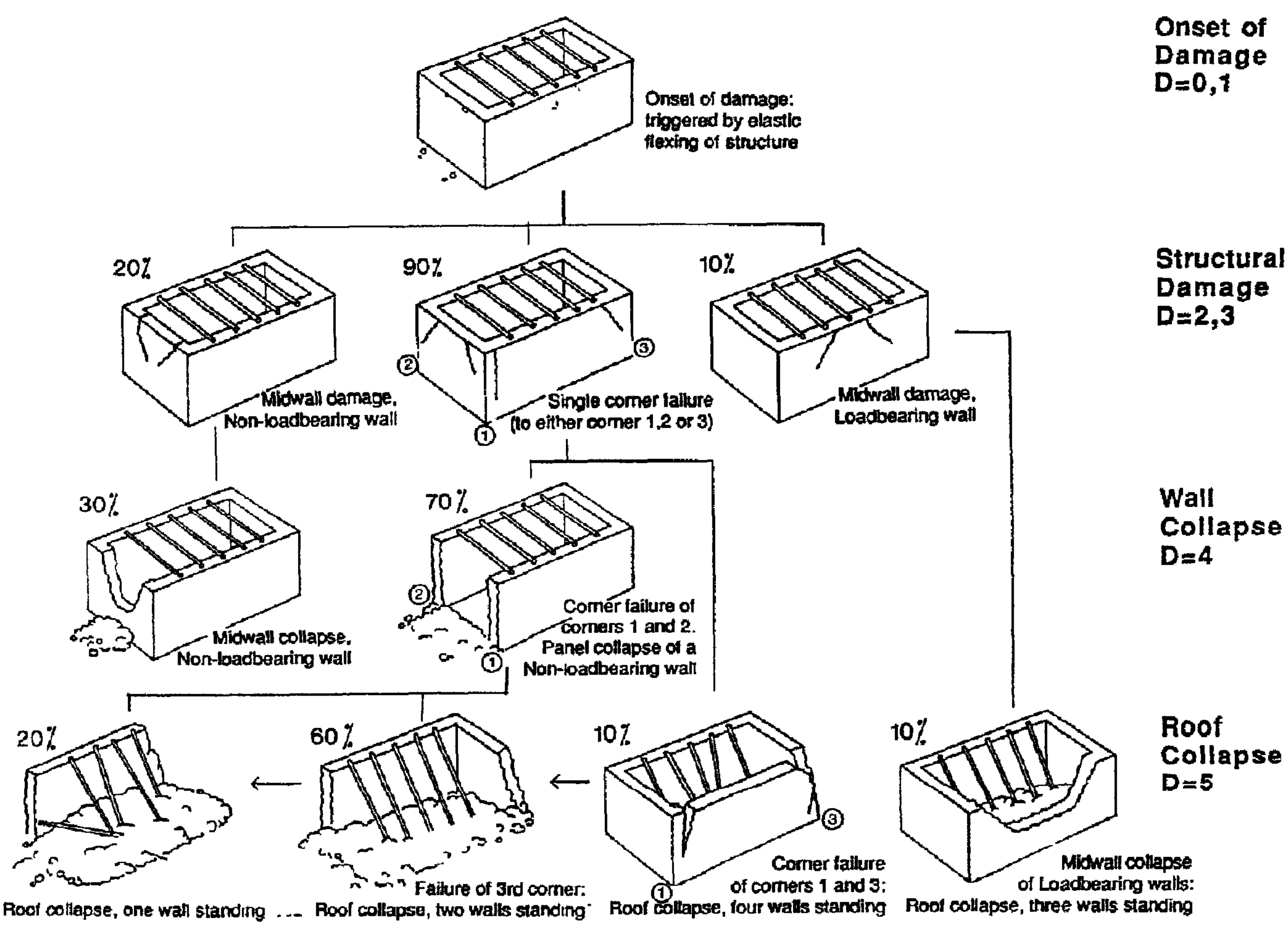

Figure 2.6 Observed Progression of Earthquake Damage