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Robin Spence

Andrew Coburn

Cambridge, May 1987

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Vulnerability of Low-Income Housing in Earthquake Areas

ODA Project R3662, Final Report

Robin Spence and Andrew Coburn

Summary

Earthquakes are a major hazard throughout much of the developing world. During this century, over one million people have been killed and about four million houses have been destroyed by earthquakes. Apart from the terrible human casualties of the earthquakes, the large reconstruction costs are constantly draining funds needed elsewhere for other capital investment programmes. This study examines possible methods of reducing future losses by concentrating on the particular situation in one high-risk area, Eastern Anatolia in Turkey, where building methods and economic conditions are similar to those in many of the areas which have suffered the greatest losses. Within Turkey, Eastern Anatolia is responsible for half the potential casualties and a quarter of the potential homeless of the country as a whole. Reducing the earthquake damage in Eastern Anatolia would significantly reduce the National total losses.

Eastern Anatolia is likely to continue to experience the level of seismic activity that it has throughout the century. Over the next 25 years, it is expected that it will experience over 40 small ($M<5.0$) earthquakes, 30 moderate ($5.0<M<6.0$) earthquakes and at least 8 large earthquakes ($6.0<M<7.0$). It is also probable that within 25 years, Eastern Anatolia will experience a very large magnitude earthquake ($7.0<M<8.0$) which would have disastrous effects. These will take place in a region of rapidly increasing population, likely to double within the 25 years.

The reason that Eastern Anatolia is more vulnerable to earthquakes than elsewhere is that the housing stock of the area is still predominantly owner-built traditional structures of weak rubble masonry. Elsewhere in Turkey, housing stock has upgraded to higher-cost, less vulnerable construction. This is mainly due to rises in income levels and standards of living that have taken place elsewhere in Turkey but for a number of reasons, these changes have been very much slower in Eastern Anatolia. The prospects for rapid rises in income levels in Eastern Anatolia in the immediate future are generally held to be poor.

Earthquake losses could be reduced by helping villagers in the areas of highest risk to build more earthquake resistant houses at low cost. A Government programme could help villagers by training craftsmen builders in earthquake-resistant construction techniques, raising public awareness of earthquake risk and possibly subsidising the additional cost of incorporating strengthening into normal construction. The costs of such a programme could be considerable, so the costs and benefits of any proposal should be carefully considered.

From examination of structural damage in a number of earthquakes, the process of damage initiation and progression in traditional stone masonry buildings can be defined. Ways of preventing damage initiation and limiting its progression are proposed for a range of costs that are appropriate to the capabilities of village builders and the construction costs of the different village building types. In construction experiments, a number of examples of strengthened stone masonry were built and costed. An Impulse Table to simulate earthquake forces on rural houses was used to test and compare the effectiveness of different methods of low-cost strengthening in full size structures.

The effect that strengthening rural construction would have on reducing future earthquake damage was calculated from average expectations of damage level derived from detailed study of the damage to past earthquakes in the study area. Quantification of vulnerability is proposed in terms of damage attenuation relationships for particular building types. The vulnerability of other building types was derived from that for stone masonry by using Relative Vulnerability Functions.

Future earthquake losses have been predicted for a number of scenarios. Based on present trends of population growth and building construction in the region, Turkey can expect to replace 70,000-100,000 rural houses in Eastern Anatolia over the next 25 years. By introducing a regional training programme for village builders these losses could be reduced by an estimated 16,000 houses. If the Government was prepared to subsidise the additional cost of adding triple hatıl strengthening to new construction, expected losses would reduce by an estimated 32,000 houses; at least a third of the total, saving twice as much in reconstruction costs as would be spent in strengthening subsidies.

The methods developed and the conclusions reached are to different degrees applicable to a large area including parts of Iran, Iraq, Afghanistan, Pakistan and India. They may also be applicable in the earthquake areas of Indonesia, Africa and South America.

Chapter One

Introduction

1.1 Objectives of the Study

During the present century, over one million people have lost their lives in earthquakes throughout the world.[1] The great majority of these deaths have been in the villages of developing countries, and studies reveal an exceptionally high casualty rate in areas where stone and adobe masonry are the predominant materials for the construction of dwellings. These are the materials traditionally used in the great Alpine-Himalayan earthquake belt which stretches from the Mediterranean countries; Italy, Yugoslavia, Romania and Greece through Turkey and Iran to Afghanistan, Pakistan and Northern India. In some of these countries rising incomes have caused a shift away from these materials and towards safer forms of construction; but in most of the area change in building technique is occurring very slowly, and it seems that that most of the village houses will continue to be built in weak masonry materials for the foreseeable future.

It is well established that such weak masonry construction is highly vulnerable to earthquake ground shaking. Even earthquakes of moderate magnitudes can result in major disasters; not only do the buildings disintegrate under relatively small shocks, but their occupants are frequently killed or trapped under the weight of the falling masonry, or suffocated by the dense clouds of dust which are generated. Casualties are an order of magnitude higher in areas where weak masonry is used than where other lighter forms of construction such as timber frame are used.[2]

The extreme vulnerability of this form of construction has been a matter of concern for many years to the people and governments of the countries most affected. Efforts to reduce the vulnerability of the rural areas have been largely ineffectual however, because they have depended on unenforceable earthquake codes, and proposals involving expensive materials and skills not available in the villages, or on radical changes in house style which have been unacceptable to the villagers. Government actions have been in most cases limited to reconstruction programmes following earthquakes rather than pre-earthquake mitigation. In some reconstruction programmes new earthquake-resistant techniques have been introduced, but the scale of such rebuilding has been too small and the techniques too sophisticated to affect rural construction generally or to reduce future earthquake vulnerability.

The extreme vulnerability of most rural areas thus remains undiminished, and with increasing population densities in many of the vulnerable areas, disasters on an ever-increasing scale are bound to recur without some reduction in the vulnerability of current village construction techniques.

The design of effective modification strategies presents considerable difficulties for Governments such as that of Turkey which propose to take such action. Any programme must be carried out on a large enough scale to make an impact on the whole region. Proposed modifications must make a significant reduction in earthquake vulnerability and at the same time be socially acceptable. The programme must also be cost-effective, designed to create the maximum benefit in terms of reduced losses for the resources which can be made available for it.

Research has a contribution to make in providing the information needed to help governments and individual houseowners plan appropriate action: in identifying existing methods of construction in the earthquake areas, and trends in new construction; in determining the vulnerability of the present and predicted future population to expected future earthquakes; and in assessing the reduction in vulnerability resulting from different alternative modifications.

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1 Rezani (1979).

2 Ohta (1980).

The Martin Centre has experience of research on earthquake vulnerability of rural buildings through field studies in Northern Pakistan and Southern Italy.[3] These studies revealed the need and the potential for vulnerability reduction. However no methods were available by which the benefits of vulnerability reduction could be measured or alternative strategies assessed. A need was therefore identified to develop simple methods of asessing vulnerability which are applicable to the data available on rural housing, and which could be applied to study the effects of modifications in construction methods.

The principal objectives of the project as stated in the original proposal[4] were:

(1) to develop methods to assess the vulnerability of low-income dwellings to earthquakes of different intensities

(2) to develop methods of assessing the benefits of modification in existing construction techniques to reduce earthquake vulnerablity

(3) to develop methods to assess the benefits of modification programmes for existing houses to reduce earthquake vulnerability

After the formulation of this proposal, a collaborative link was established with the Turkish National Committee for Earthquake Engineering to study vulnerability of rural housing in Turkey. As a result the scope and objectives of the research were expanded in a number of ways.

1) The selection of Turkey as the study area meant that considerable published data on seismic hazard was available. Using this data, the scope of the research was able to be enlarged to include the prediction of future earthquake losses for rural areas, and to study loss reduction in the framework of cost-benefit analysis of alternative mitigation strategies.

2) After initial literature and field studies it became apparent that no data existed from which to assess the benefits of certain key low-cost strengthening methods. A programme of structural testing was therefore planned to supply this data, and this became a major element of the project. The tests were planned in order to make direct comparisons between the performance of full-scale test structures of masonry of different types under both static and dynamic loading. They also provided an opportunity to observe traditional construction techniques at close quarters, to determine the costs involved, and to assess the viability of proposed construction techniques for use by village builders.

3) Within the duration of the project, the opportunity arose to conduct field studies of the damage following four earthquakes in Turkey affecting areas in which the predominant material of construction was stone masonry. These studies provided an opportunity to study the mechanism of structural damage and collapse for traditional stone masonry at greater depth than in any previous study.[5] A methodology for damage surveys was also developed through these field studies.[6]

4) A further field study was conducted in an area where a major earthquake had occurred 11 years previously, in order to study the effectiveness of government reconstruction policy and the reconstruction efforts of the people affected.[7]

5) It became apparent that modification programmes for existing houses were unlikely to be of practical relevance in the study area selected, and the third objective of the original proposal, that of considering modifications to existing houses, was not pursued.

The project thus developed beyond its original methodological objectives, into a broad-ranging study of the seismic risk and of alternative mitigation policies in a particular high risk region.

The study was conducted in parallel with a complementary project on the socio-cultural aspects of housing in earthquake areas, carried out by Oxford Polytechnic, also sponsored by British

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3 Coburn, Hughes, Illi, Nash and Spence (1982) and Coburn, Hughes, Nash and Spence (1982).

4 Vulnerability of Low-Income Housing in Earthquake Areas, Project Proposal (1981).

5 Coburn and Akkaş (1983), Coburn and Hughes (1983), Coburn and Hughes (1984), Coburn (1987).

6 Coburn (1985).

7 Coburn, Leslie and Tabban (1984).

Overseas Development Administration. This project was based on fieldwork carried out in Western Turkey.[8]

1.2 Choice of Study Area

The choice of Turkey for the field study arose as a result of an invitation from the Turkish National Committee for Earthquake Engineering to collaborate with them on studies contributing to government efforts to reduce rural earthquake losses in Eastern Anatolia. The collaboration involved close ties with two research institutes already active in this field. These were the Earthquake Engineering Research Center at Middle East Technical University in Ankara, whose Director Professor Mustafa Erdik is Secretary of TNCEE, and the Earthquake Research Department of the Ministry of Public Works and Housing also in Ankara, whose Director General Dr. Oktay Ergünay is also a member of TNCEE. The extensive previous research and data collection of these two research institutes on earthquake hazard, building types and earthquake damage in Turkey were of great value to the project.

Because of the large differences in earthquake risk which exist between different parts of Turkey, it was decided to concentrate the study on one particular high-risk area. Eastern Anatolia was chosen as the study area for the following reasons:

(1) Eastern Anatolia is one of the areas of severest earthquake hazard in Turkey, as shown by the official earthquake zoning map, figure 1.1. On this map, the zones are distinguished according to the largest earthquake intensity likely to be experienced. In Eastern Anatolia, there are two bands of Zone I and II, corresponding to intensity VIII or more, which meet in a large zone of high seismicity in the Provinces of Bingöl, Kars, Bitlis, Erzurum, Ağrı, Muş, and Van. Within these provinces there have been six earthquakes with magnitudes exceeding M_s=6.0 during the last 20 years.

(2) The area is one of predominantly stone masonry construction. Figure 1.2 shows the distribution of rural building types in Turkey, indicating the disparity between the west, where timber, brick masonry and reinforced concrete are widely used, and the east where they form a very low proportion of the building stock. In the six high-seismicity provinces listed above, stone and adobe masonry account for over 85% of rural houses.

(3) The combination of high seismicity and weak masonry building makes this an area of potentially very high losses and casualties. Figures 1.3 and 1.4 have been prepared to show the Potential Homeless and Potential Casualties in rural areas, province by province. These two measures of the population at risk have been derived from the two previous maps by assuming for each building type damage levels typical of the most severe intensity anticipated, and estimating the number of people affected by unrepairable damage or collapse of their houses. The particularly high concentration of losses in the region defined can be clearly seen. The six provinces contain 10% of Turkey's land area and only 6% of the population; but this small area contains 25% of all the Potential Homeless, and 50% of the Potential Casualties in the entire country.

(4) Future levels of risk in the region are equally great. Eastern Anatolia is an area of rapidly expanding population. Figure 1.5 shows relative population growth rates province by province. Most of the areas of highest growth are located around the expanding cities particularly in the west, and are due to rural-urban migration. Despite net out-migration from Eastern Anatolia, population growth rates are still well above the national average. It is also an area where there is little change in methods of construction, as indicated by the small proportion of houses built in modern materials. Thus the Potential Homeless and Casualties in the region can be expected to rise and to increase as a proportion of those in the country as a whole.

It is evident from these considerations that any action to reduce future earthquake losses in Eastern Anatolia would make a significant contribution to reducing losses in the country as a whole. The study area was therefore defined to include the whole of this high risk area, and some of the

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[8] Aysan and Oliver (1987).

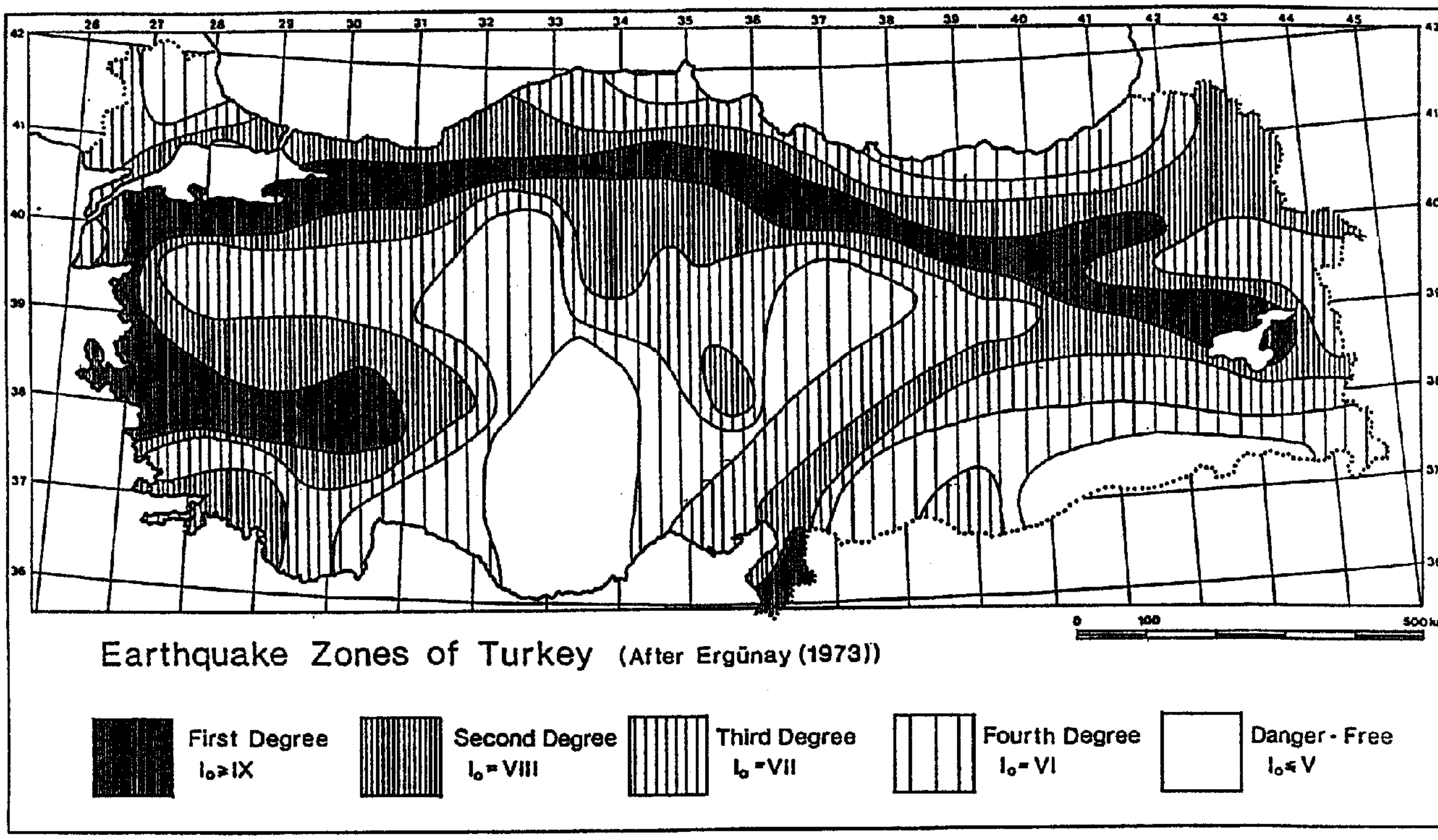

Figure 1.1 Earthquake Zones of Turkey

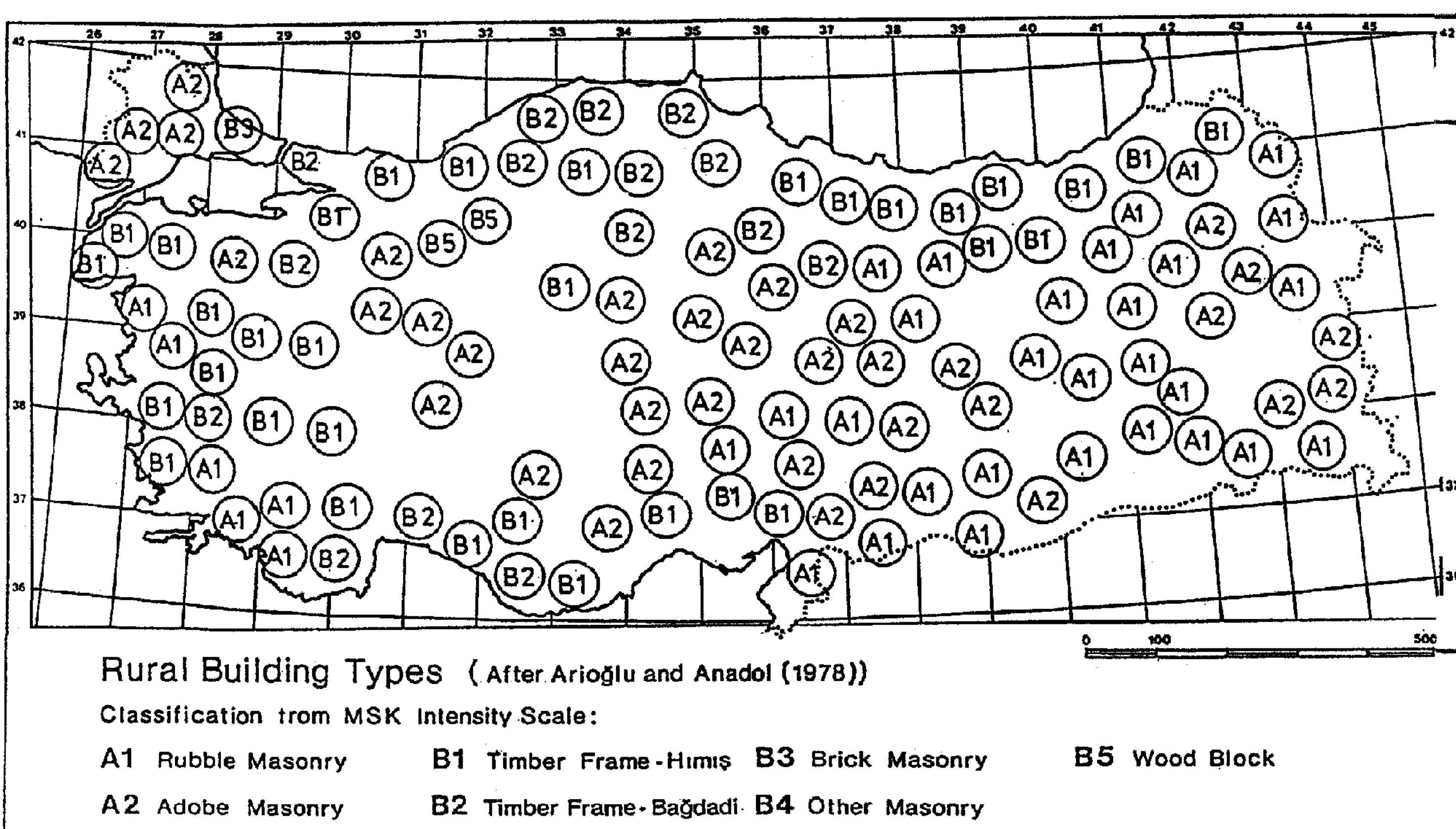

Figure 1.2 Rural Building Types

adjacent provinces with similar building types and conditions. The study area so defined is shown in figure 1.6.

1.3 General Description of the Study Area

The study area has been extensively visited and mapped. Typical villages in the area have been studied in detail and methods of building construction in the villages have been documented. During the course of the research, four field studies were carried out in the study area, involving a total of 33 man-weeks in the area by members of the UK project team, working in all cases alongside staff of the Turkish collaborating institutes. An estimated 300 villages in the study area were visited.

The results of these field studies have been reported in detail in separate publications.[9] In this section a brief general description of the area will be given. The building technologies used will be disussed in the next Chapter.

Eastern Anatolia is an upland area, lying at the intersection of two major mountain ranges, the Taurus Mountains running SW-NE containing the East Anatolian fault system, and the Pontic Mountains running East-West, containing the North Anatolian fault system. Almost the whole land area lies at an altitude exceeding 1,000m, with peaks exceeding 3,000m. Between these peaks fertile basins provide areas for productive cultivation. The region is drained by two major river systems, the Firat and the Murat, the first steeply incised, the second flowing through a series of basins. The climate is extreme, with average summer temperatures in the range 20-25°C, and winters of -5 to -10°C with heavy snow, and up to 150 days of frost per year. Annual precipitation averages around 500mm.

The total population of the area at the last census was about 5.5 million,[10] an average population density slightly in excess of 30 persons/km^2. The population is mainly rural (between 52% and 77% in the individual provinces) and concentrated in the fertile areas. The average population growth rate is just above 2%.

Only 8% of the land area is arable; this is mainly farmed in individual family smallholdings on which the main crop is wheat supplemented by vegetables, but the main economic activity of the area is the herding of animals (sheep, goats and cattle) on the vast upland pastures. Most families own substantial flocks, which they rear both for their own consumption and for sale to generate cash income. Livestock also represent savings, and may be sold to pay for a wedding or for the construction of a new house. There is little formal industry, and the other sources of income are handicrafts, and the remittances from migrant workers in the industrial cities to the west or overseas.

Prospects for rapid increases in per-capita income from these sources which would lead to higher-cost less vulnerable housing stock are generally held to be poor.[11]

1.4 Choices for Mitigation

With little prospect of a rapid improvement in building stock occurring naturally in Eastern Anatolia, there are a number of methods that might be considered by the National Government, based on its present policies, to bring about improvements. These might include providing houses, legislated building controls or aided self-help schemes.

Housing Provision

The Turkish Government at present provides houses for the homeless after earthquakes and in cases of villages suffering social or physical hardship, for example the relocation of villages endangered by rockfall or flooding. The extension of this policy to cover earthquake risk is impractical because of the sheer scale of hazard involved. To rehouse the rural population of Eastern Anatolia living in earthquake Zone I alone would require a budget far in excess of the likely losses from earthquakes

9 Coburn (1982b), Coburn (1987).

10 State Institute of Statistics (1980).

11 See the review of planning reports on economic prospects for Eastern Anatolia in Coburn (1987).

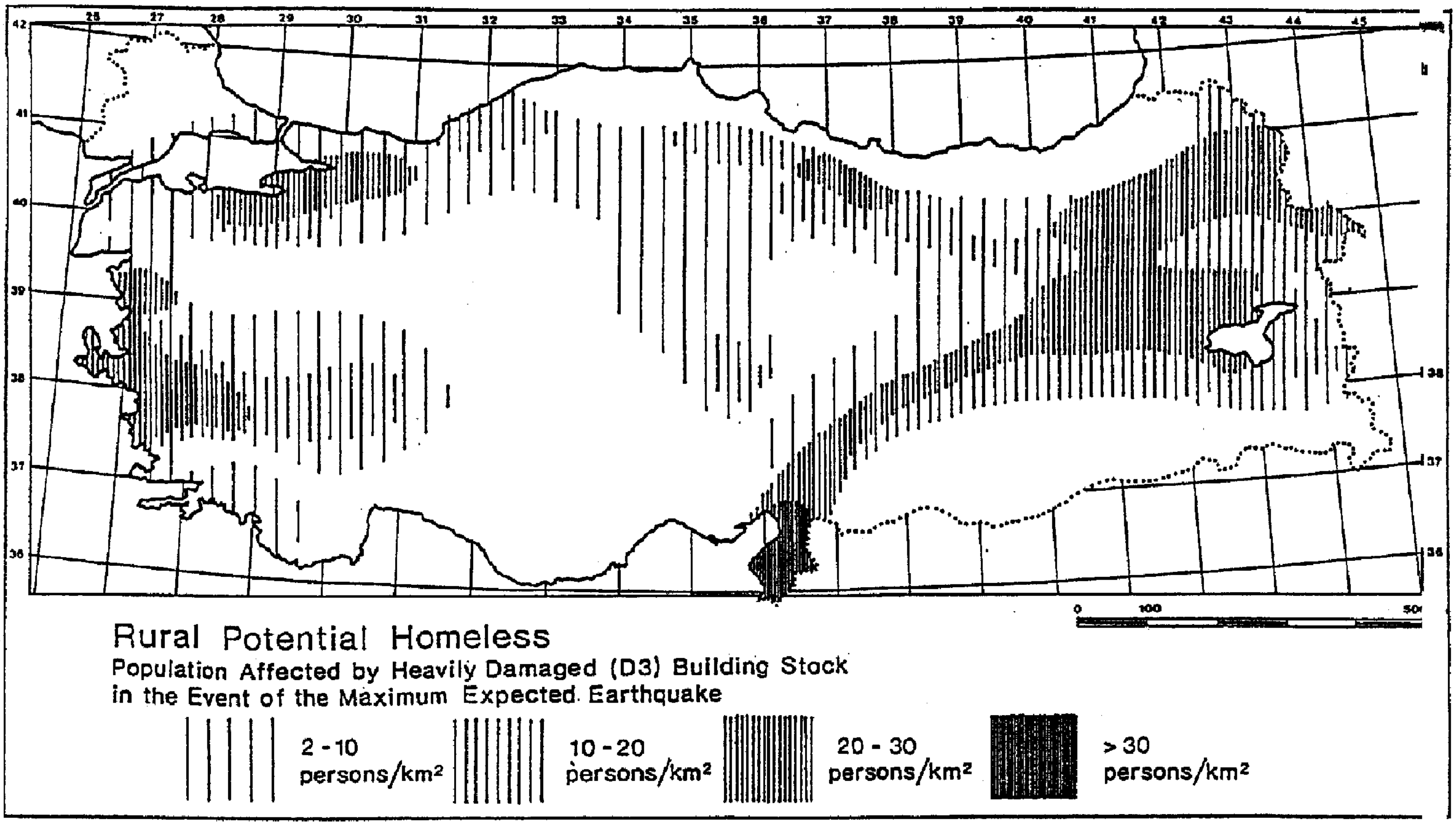

Figure 1.3 Rural Potential Homeless

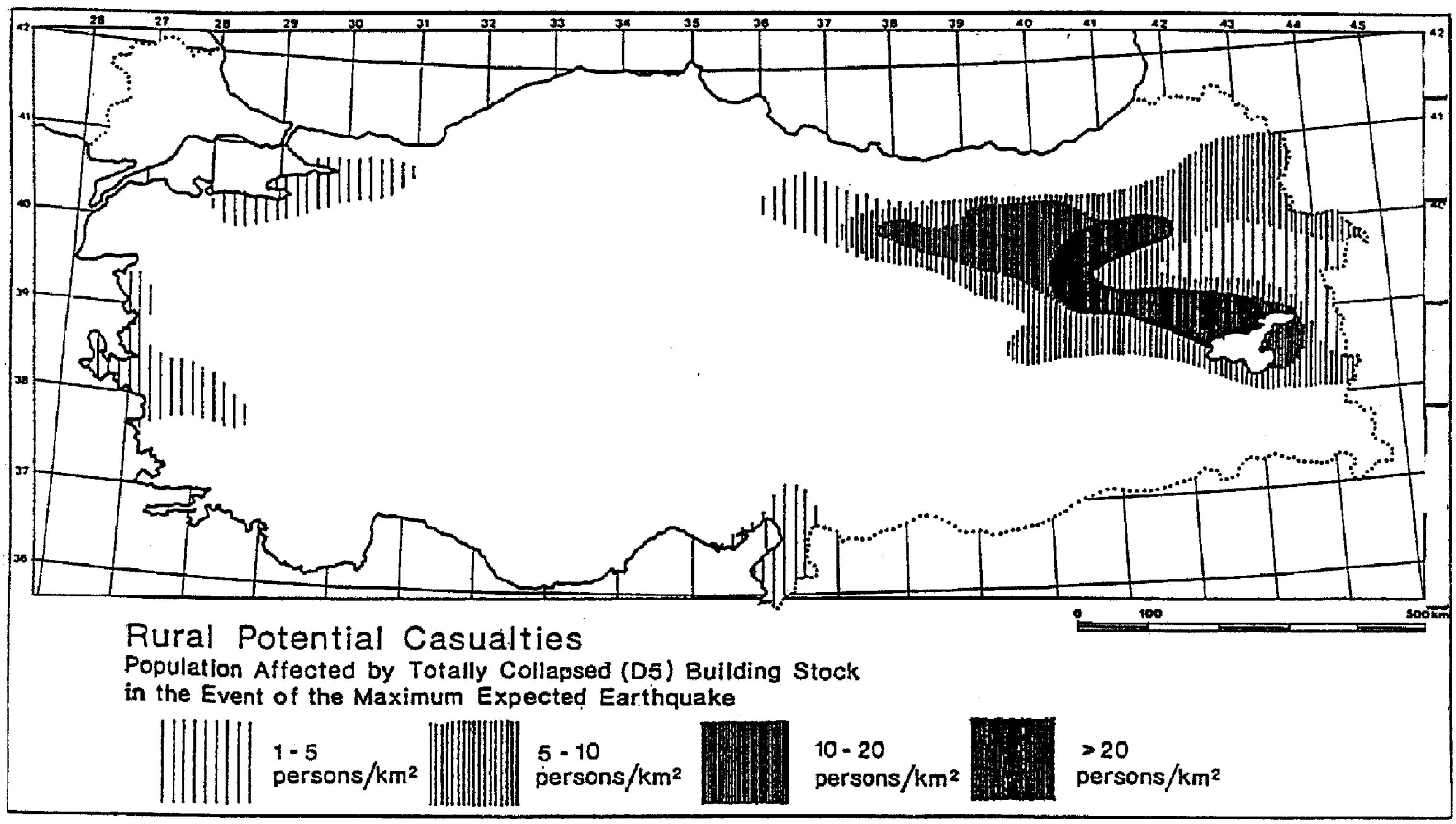

Figure 1.4 Rural Potential Casualties

over a very long time. It would also be only short term, since as the population expanded or ageing houses needed to be replaced, even more houses would be needed.

Legislated Building Controls in the Villages
Extending present building regulations from the municipalities is similarly impractical. The necessary administrators and engineers to check that construction complies with building codes are already in short supply in the cities and very many more would be needed to enforce building standards in the thousands of villages involved. It is also generally accepted that present building codes are not appropriate to the low-cost construction carried out in most villages. The high cost of complying with these building codes would mean either that many villagers were prevented from building at all, or that codes were unenforceable without financial help.

Aided Self-Help
An alternative to the enforcement of minimum code standards is to encourage villagers to improve the quality of construction of their traditional houses. This could be carried out by training the village builders in low-cost methods of improving traditional construction and encouraging house owners to incorporate the maximum level of strengthening they can afford. There have been some successful cases of training village builders in low-cost earthquake-resistant construction in other countries.[12] This type of programme would involve a major public education project to make houseowners aware of the earthquake risk and to encourage them to protect themselves and their families to the maximum extent possible. This would have to be coupled with the training of craftsmen builders, at least one from every village, which could be carried out at regional training centres in the highest risk areas.

Subsidised House Strengthening
Inevitably, however, one of the main restrictions on the widescale adoption of strengthened building construction is the cost of doing so. It will be shown later in this report that if the Turkish Government were to subsidise the cost of adding additional strengthening to traditional construction across the highest risk areas (Zones I, II and III), it would save reconstruction costs in excess of the subsidies paid out. Subsidising the strengthening of traditional house construction could be carried out in a similar administrative way to that used for 'aided self-help' reconstruction.[13] Building materials or credits could be made available, conditional upon a houseowner employing a builder trained in earthquake-resistant techniques and achieving a certain minimum specification of house strengthening. The owner should also be encouraged to incorporate higher levels of strengthening if he can afford to do so. A practical and effective programme for reducing earthquake losses in Eastern Anatolia would therefore consist of:

(a) A general programme to increase informed awareness of the hazards among the population and building professionals in the earthquake areas.

(b) Definition of techniques for strengthening the houses that are being constructed in the villages, to resist earthquake forces;
 (i) using familiar materials.
 (ii) using methods within the capability of the village builders.
 (iii) at costs commensurate with normal costs of construction.

(c) Establishment of training courses for village builders to a level at which they are proficient in these techniques without supervision.

(d) The possible creation of an administrative system to implement and control house strengthening grants for villagers in earthquake areas building a new house. Villagers could apply for a financial grant towards the cost of making their house more earthquake-resistant. This grant would be conditional on employing a trained village builder and carrying out strengthening measures to an agreed specification.

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12 See for example the Building Education Project in Yemen Arab Republic, described in Leslie (1984) and Coburn and Leslie (1986). A number of building education projects are also reviewed in Cuny (1983).

13 The legal framework for 'aided self-help'; the cooperation between the individual and the state, is described in Gülkan and Ergünay (1984).

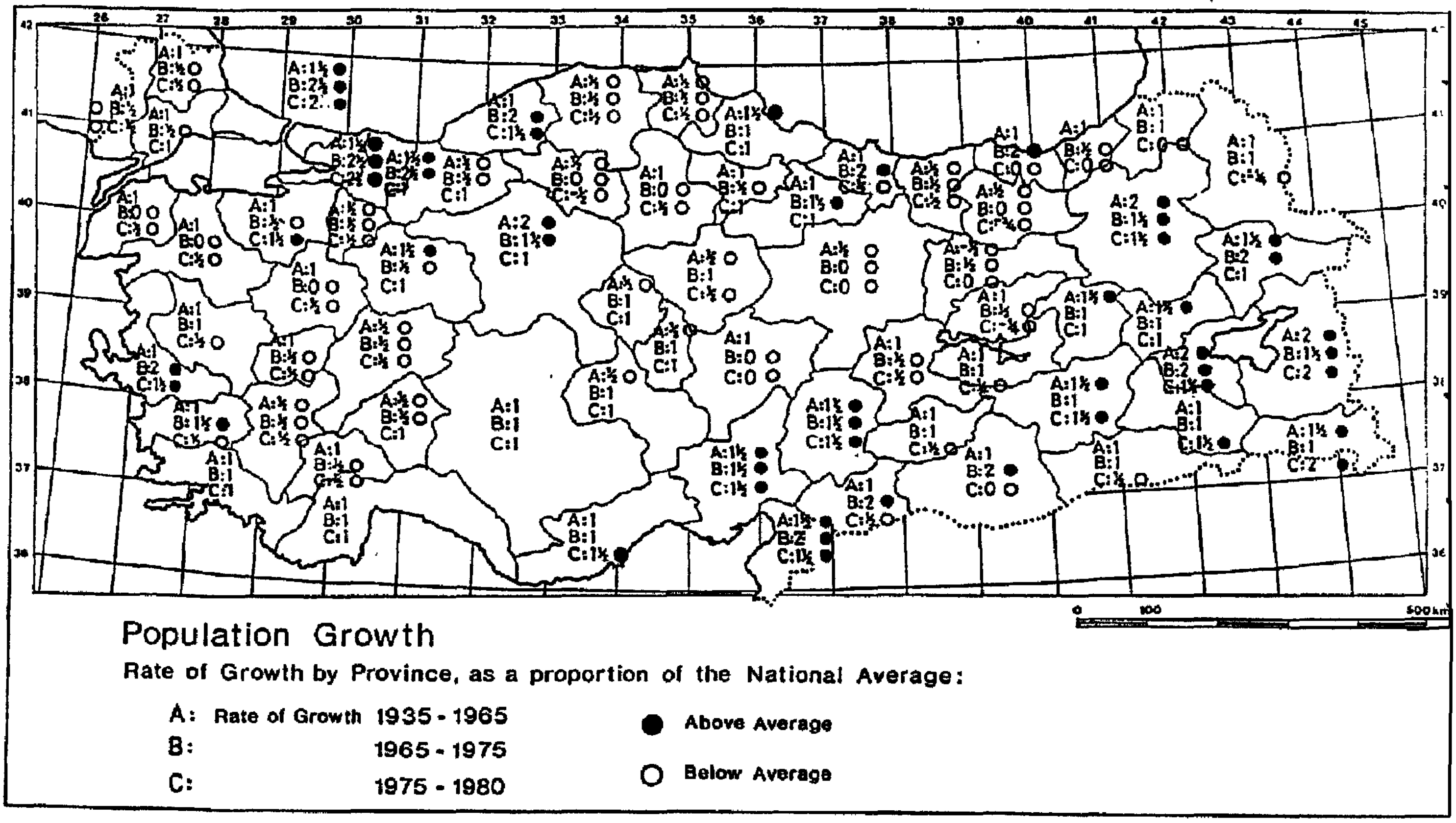

Figure 1.5 Population Growth

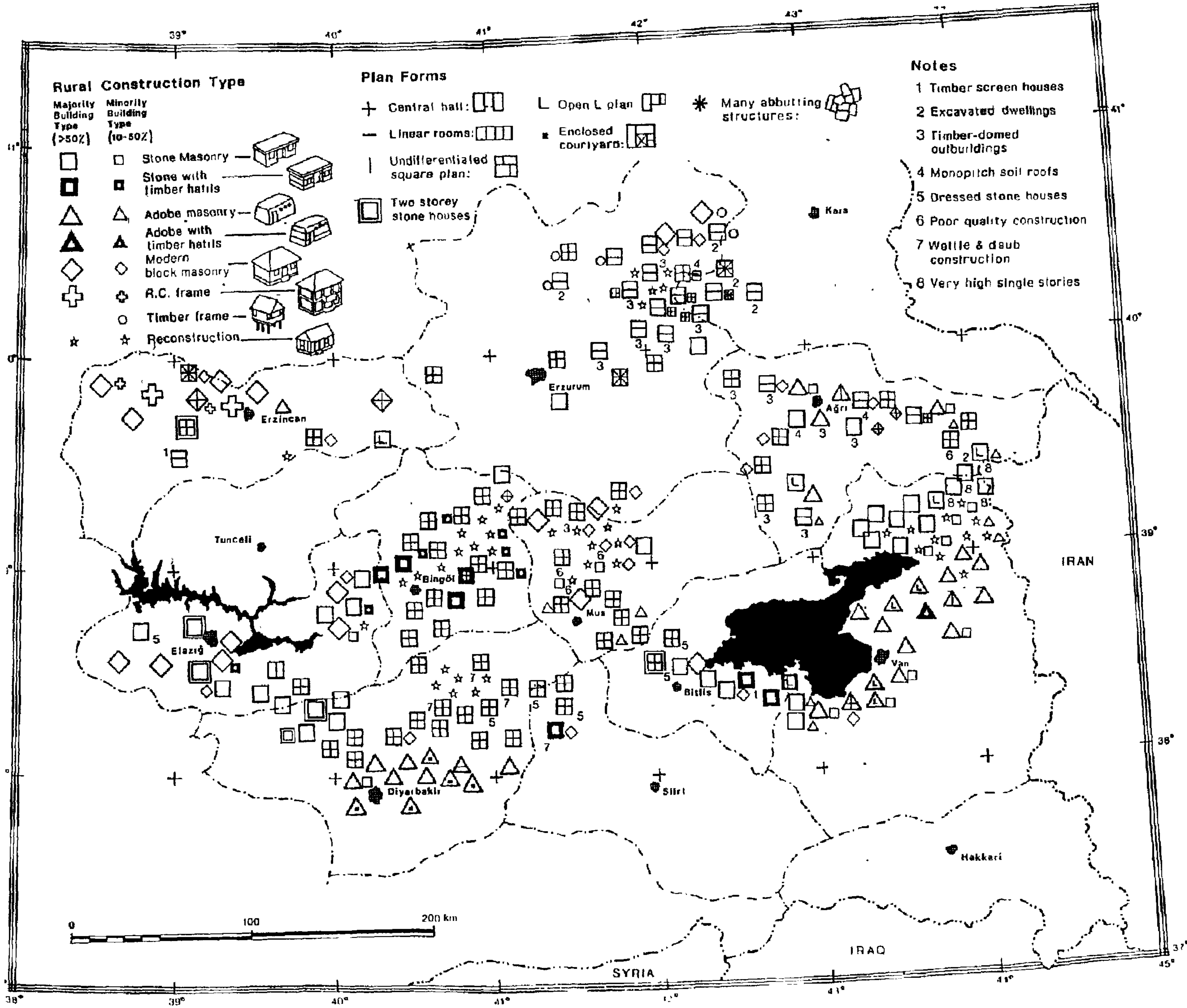

Figure 1.6 The Study Area: Rural Building Types