VULNERABILITY AND SEISMIC RISK REDUCTION FOR RURAL HOUSING IN TURKEY

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SUMMARY

The paper presents methods for evaluating vulnerability, seismic risk and the costs and benefits of modifications in traditional construction techniques, and applies the methods to a particular area of high seismic risk, Bingöl Province, in Eastern Turkey. It is shown that a general modification programme which achieved relatively modest strengthening could be expected to be a cost-effective alternative to replacement of lost buildings after earthquakes. Some practical implications of such a modification programme are also considered.

INTRODUCTION

Stone and adobe masonry houses are characteristic of the rural areas throughout most of Eastern Turkey. The materials are freely available, the building skills are established, and the houses are well-adapted to the climate, with its extremes of temperature. These houses are notoriously vulnerable to earthquakes: well over 100,000 have been destroyed by earthquakes in Eastern Turkey this century, killing over 50,000 people. Figure 1 shows the locations of major earthquakes and building types in Eastern Turkey. There has been some movement in recent years towards concrete block walls and lighter-weight pitched roofs, but these require expensive modern materials, and it seems inevitable that stone and adobe buildings will predominate for some time to come.

After major earthquakes since 1966, rehousing for those whose buildings were destroyed has taken the form of prefabricated units, with longer-term resettlement in contractor-built housing in newly planned, relocated villages, using modern materials. This policy has proved expensive, and has had only mixed acceptance. Alternative approaches are currently being considered, including the wider use of self-help techniques in reconstruction, and strengthening new construction in the areas of high risk. Since building codes and recommendations cannot be enforced in these areas, the contribution of government must be planned to stimulate the participation of the local people. One aspect of risk reduction planning is to study the cost and benefits of alternative methods of strengthening buildings so that cost-effective modification strategies can be developed. It is primarily this aspect which will be considered in this paper.

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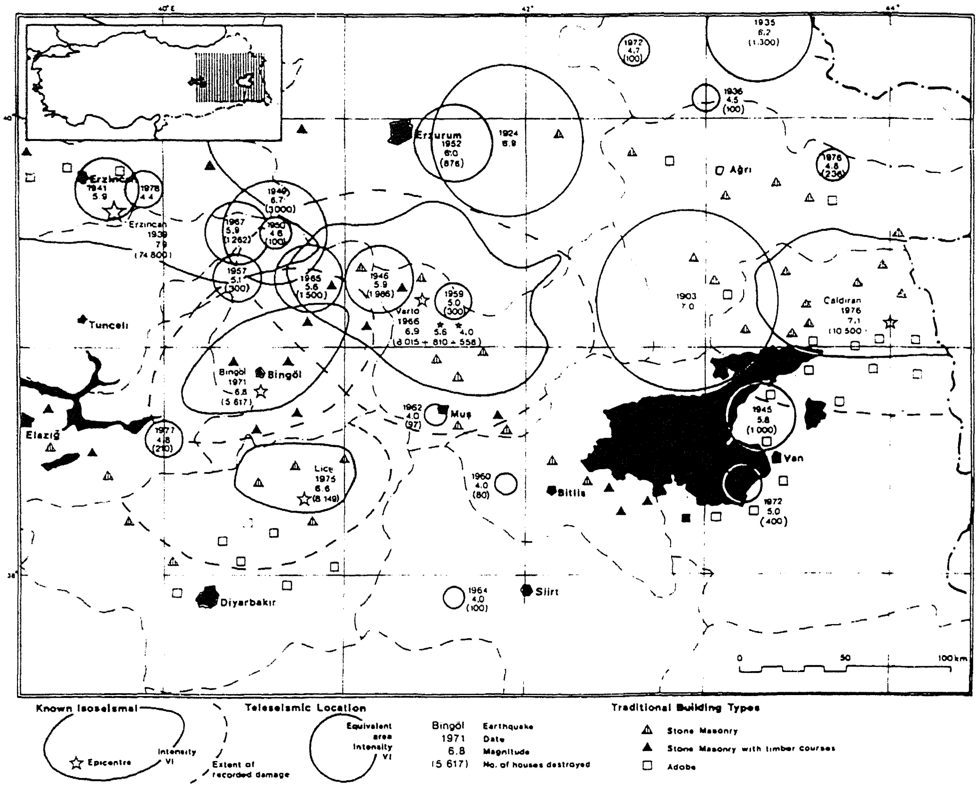
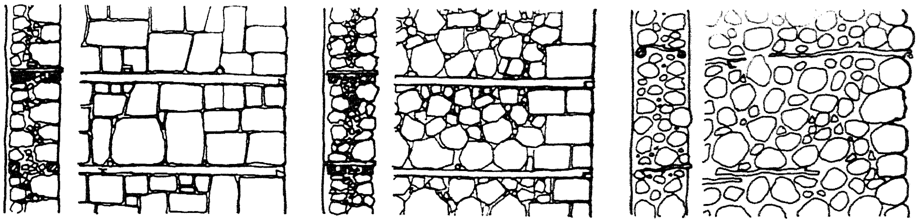


Figure 1. Locations of Damaging Earthquakes 1900-1983 (Ref. 1) and Regional Building Types.

TRADITIONAL BUILDINGS AND MODIFICATION STRATEGIES

The most commonly occurring house type in the Bingöl region consists of a detached, single storey random-rubble stone masonry structure with a thick, flat mud roof on timber joists. The house has a number of rooms, added at different stages in its history, and often abutting stores and animal sheds. Variations on this general pattern occur throughout Eastern Turkey in a number of architectural expressions and configurations. Characteristic of most of the building traditions are a common structural system of room size, wall lengths, heights and roof span dimensions. The appearance and layout of the traditional house is more standardised than are materials of construction and building techniques. The major variation in the structural characteristics of houses within villages and between villages is in the quality of construction of the loadbearing masonry walls. A number of grades of stone masonry are found, from rounded, riverbed stones set in thick mud mortar, through knapped, angular rocks fitted with mortar infill, to dressed stone facing blocks, scribed together in courses, Fig. 2.



1 Dressed, coursed stone.
Large units, narrow joints, and little mortar.
Each block in a stable position.
Finished, shaped timber, (if timber used at all) cross-tied with butterfly corner joints.

2 Knapped, angular stone.
Regular sizes, coursed.
Double skin with mud mortar between.
Sometimes dressed stone quoins at corners.
Larger stones towards base.
Finished, shaped timber with lapped joints.

3 Round stones in deep mud mortar.
Usually with thick mud-and-straw render.
Irregular and discontinuous timber courses, if any.

Figure 2. Variations in Traditional Stone Masonry Construction

The performance of stone masonry houses in earthquakes is highly dependent on the quality of construction of the structural walls. Unreinforced stone and adobe masonry with mud mortar are brittle and weak in tension. Frequently large cracks are present in a structure even before an earthquake because of ground settlement, deformations during construction and other factors. In an earthquake roof collapse is commonly brought about by disintegration or overturning of loadbearing walls under out-of-plane forces following corner separation from adjacent walls. The most effective way to strengthen such buildings is to improve wall construction. The climatic requirements and conventions governing house layout and appearance mean that alternative strengthening measures, such as reducing roof mass, controlling the size and positioning of openings, and introducing redundant roof support systems, are likely to be less acceptable. Improvements to wall construction should aim first, to create greater structural integrity, so that the initiation of cracking does not lead rapidly to disintegration of the wall; and secondly, to improve the horizontal continuity of each wall, and especially at wall-to-wall junctions, so that the out-of-plane forces acting on each wall can be transferred to adjacent perpendicular walls.

In some parts of the region there is a tradition of placing horizontal timber courses or hatils at approximately 90 cm intervals up the walls, Fig. 2. Where these have been continuous and well-jointed they appear to have reduced the level of earthquake damage significantly both by halting crack propagation and maintaining the integrity of the wall-to-wall corner connection. One possible improvement would be to encourage the wider and more effective use of such hatils. The same effect could be achieved by means of concrete ring beams placed at the level of the ground floor and the eaves. In either case the roof joists would be connected to the upper beam to prevent slipping and disintegration of the roof.

Other improvements, which would certainly improve the earthquake resistance of traditional structures, are the use of a reinforced concrete foundation; the use of improved mortars; and the replacement of the mud and timber roof with a reinforced concrete roof slab. Some of these improvements and their costs, are shown in Table 1, based on a traditional 3-roomed house of 14 m x 9 m. Table 1 also shows the approximate cost of rehousing the occupants of the standard house in a prefabricated house if it was heavily damaged in the earthquake. The modification cost ratio (MCR) or ratio of cost of modification to rehousing in a prefabricated building is also indicated.

Description	Approximate cost (TL)	Modification cost ratio, MCR (%)
Traditional stone masonry house, 14 m x 9 m	300,000	20.0
Additional cost of three standard timber hatils*	80,000	5.3
Additional cost of two reinforced concrete ring beams, and reinforced concrete foundations*	150,000	10.0
Additional cost of cement instead of mud mortar*	90,000	6.0
Replacement by prefabricated house 7.5 m x 6.5 m	1,500,000	100.0

* materials cost only

Table 1: Alternative modifications and modification cost ratios

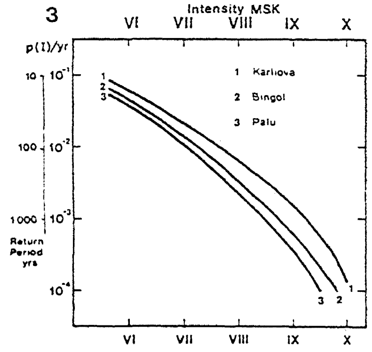
SEISMIC RISK

The specific risk for a house, or population of houses, may be defined as:

$$r_j = \sum_i H_{ij} V_i \qquad (1)$$

where H_{ij}, the seismic hazard, is the annual probability of an event of "intensity" i at point j, and V_i is the vulnerability of the building population to that event, expressed in the form of a specific loss (Ref. 2). The use of macroseismic scales as a measure of the seismic hazard is theoretically questionable, since intensity levels are largely derived from building damage data; an alternative, quite independent parameter such as peak ground acceleration would be preferable. However present data on the relationship of building damage to ground motion parameters are inadequate, and no acceleration attenuation curves derived from Turkish records are available. Intensity attenuation data, though confused by the variety of building types, are based on local earthquake records; in effect, the use of these intensity recurrence relationships is equivalent to using the past damage history of an area to predict future damage. Macroseismic intensity, using the MSK scale, will therefore be used in this paper.

The intensity recurrence data used here are derived from recent work by Erdik et al. (Ref. 3). Figure 3 shows the intensity recurrence rates for the three points in the 30 Km square grid nearest to the towns of



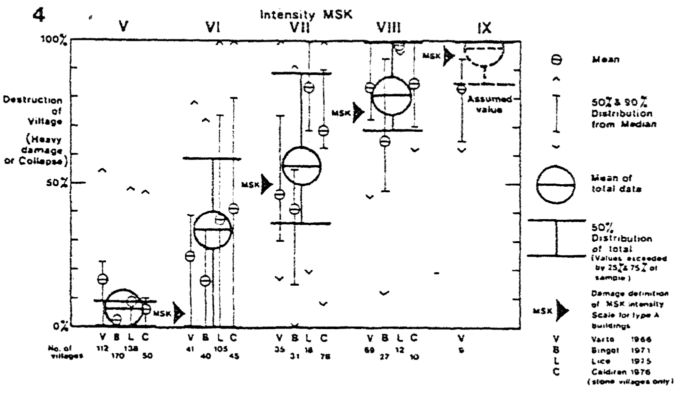


Figure 3. Intensity Recurrence Rates for Study Area (Ref. 3).
Figure 4. Damage Ratios for Stone Masonry Villages in Past Earthquakes.

Bingöl, Palu and Karliova. It shows that there are significant variations within the province; this is due to its location near the junction of two different seismic source zones, the active North Anatolian fault zone and the equally active but more distant East Anatolian fault zone. The measure of vulnerability used is a damage ratio (DR) expressed as the proportion of buildings requiring complete replacement (heavily damaged or collapsed buildings). Specific risk, in equation (1), is then defined as the annual damage ratio, or the proportion of houses in the population requiring complete replacement.

Figure 4 shows the damage ratios, defined as above, derived from damage records for four recent earthquakes affecting stone masonry buildings. For each area assigned a certain intensity level, the mean value and distribution of the damage levels of all villages within the area are shown. This includes the values exceeded by 25% and 75% of the villages in each sample. Using the data of Fig. 3 and Fig. 4 the mean seismic risk has been calculated using equation (1) for each of the twenty grid points within Bingöl Province, and hence the seismic risk contours shown in Fig. 5 have been derived. As an indication of the wide spread of damage levels, a seismic risk contour is also plotted for the lower quartiles, that is, the seismic risk exceeded in 75% of villages. The highest values are in the northeastern part of the Province, which is close to the North Anatolian fault zone: at Karliova the mean risk is over 3% per annum. In the whole Province the total number of houses known to have been lost in the years 1900-1980 is about 17,000, which, making due allowance for population changes given in Ref. 1 represents an average annual loss of about 1.0%; this compares with the seismic risk map, Fig. 5, which indicates an average annual risk in the same area of 2.5%. It is probable that the true loss is somewhat higher than that based on existing records; while the true risk in this area is probably somewhat lower than that calculated, on account of the common use of timber hatils in this particular zone (Fig. 1); the

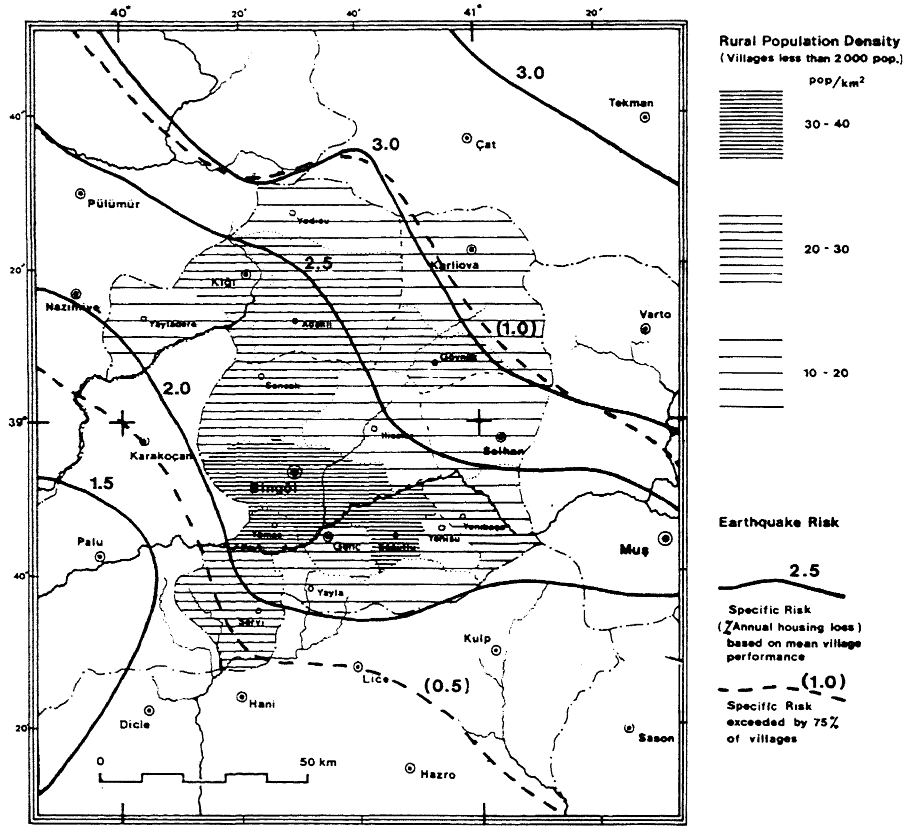


Figure 5. Seismic Risk in Bingol Province.

methodology for calculating hazard and vulnerability is based on relationships averaged over a wide range, and precise risk assessment cannot be expected; probably the true mean risk in Bingöl Province is between 60% and 75% of that shown in Fig. 5.

ECONOMIC COST AND BENEFIT OF HOUSING MODIFICATION

The economic benefit of a housing modification programme designed to reduce earthquake risk can be written:

$$PNB = PCR\,(RU - RM) - CM \qquad (2)$$

where PNB = present value of net benefit
PCR = present value of reconstruction cost
CM = cost of modification
RU = specific risk for unmodified houses
RM = specific risk for modified houses

All these values may be taken to apply to a single building or to the average of a population of buildings. Assuming RU, RM and CR do not change with time, then

$$PCR = a_n . CR$$

where a_n is a constant which depends on the time-span considered, and the discount rate. For positive net benefits, from equation (2)

$$PCR\ (RU - RM) > CM$$

$$\text{or} \qquad MCR < a_n(RU - RM) \qquad (3)$$

where $MCR = \frac{CM}{CR}$, the modification cost ratio.

The economic modification cost ratio is therefore a simple function of the reduction in annual risk, and the inequality (3) can be used to evaluate alternative building modification strategies, if the risk reduction is known.

For the present, since the risk reduction achieved by different modification strategies is not known, two hypothetical strategies will be considered. In the first (Strategy A), it will be assumed that the risk is reduced to the present lowest quartile level, i.e. that now exceeded in 75% of villages. In the second (Strategy B) it will be assumed that the risk is reduced to zero. Strategy A can be assumed to be technically attainable, while Strategy B is the theoretical limit, not technically attainable. At what modification cost ratio would each of these programmes show a net economic benefit?

Table 2 shows the levels of risk for the unmodified and the modified houses, the risk reduction, and the economic MCR (1) assuming a discount rate of 10%. An alternative MCR (2), assuming risk reduction is only 60% of that calculated, is also shown. In the area of densest population, around Bingöl, Strategy A is worthwhile if the MCR does not exceed 8-14%, while Strategy B requires an MCR not exceeding 13-22%. Put another way, assuming that the cost of a replacement house is 1,500,000 TL it would be economic to spend up to about 150,000 TL per existing or new house on a strengthening programme that reduced the risk level to that of the best 25% of existing villages; but expenditure greater than about 300,000 TL would not be economically justified even if it eliminated all losses completely.

		STRATEGY A				STRATEGY B		
				MCR %			MCR %	
	RU	RM	RU-RM	(1)	(2)	RU-RM	(1)	(2)
Karliova	.033	.011	.022	22	13	.033	33	20
Bingöl	.022	.006	.014	14	8	.022	22	13
Palu	.010	.003	.007	7	4	.010	10	6

Table 2: Risks and economic modification cost ratios for alternative hypothetical modification strategies

HOUSING MODIFICATION STRATEGIES

The modification of existing building types to eliminate all risk is not technically feasible, and the reduction of risks to very low levels is excessively costly. Reduction of earthquake risk cannot be taken as the sole criterion for a housing modification programme; social acceptability, availability of materials and skills, and administrative requirements must be considered; and improvement programmes should aim to increase both durability and comfort as well as strength.

The foregoing analysis has shown that, in the high risk areas, a general programme of strengthening which achieved a risk reduction apparently well within the capability of the existing technology would probably be cheaper than rehousing the victims of an earthquake in prefabs. It would also, of course, save many lives, and greatly reduce disaster relief, though no attempt has been made to calculate these benefits. The analysis suggests that the lower levels of strengthening will bring the greatest economic benefits. Table 1 has indicated some of the strengthening methods, costing up to 10% of the replacement cost, which might be adopted. A knowledge of the effect on the vulnerability function of the various strengthening methods would enable a housing modification programme to be specified in terms of the acceptable damage ratios at different levels of intensity or peak ground acceleration.

In practice, a housing modification programme would need to be carried out over an implementation period, by the inclusion of strengthening measures and better materials at the time of construction or rebuilding since the incorporation of strengthening into existing buildings is unlikely to be technically sound or economically justified. Any upgrading programme would imply participation from the government in providing grants for materials, training programmes for local builders and supervision to ensure some control of construction standards. To increase the initial effectiveness of the programme it should be concentrated on areas of denser rural population or rapid population increase, and in villages with poorer standards of construction.

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REFERENCES

1. Ambraseys, N.N. and Jackson, J.A., "Earthquake hazard and vulnerability in the north-eastern Mediterranean", Disasters 5 (4), pp.355-368, 1981.
2. UNDRO, Natural disasters and vulnerability analysis, Report of Expert Group Meeting, Geneva, 1980.
3. Erdik, M., Doyuran, V., Gülkan, P., Akkas, N., A probabilistic assessment of the seismic hazard in Turkey, Report No.83-1, Earthquake Engineering Research Center, Middle East Technical University, Ankara, 1983.