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Earthquake vulnerability, loss and risk assessment in Turkey

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ABSTRACT: This paper is an overview of the earthquake hazard and risk in Turkey. Several themes are addressed. A historical perspective and description of the current status of earthquake damage assessment is provided first. We emphasize that derivation of homogenous vulnerability functions for building damage must hinge on a reliable database calibrated on structural engineering criteria, and fine tuned with vernacular experience. A recent version of the damage assessment form for post-earthquake surveys is described. Vulnerability functions derived from surveys during the last 30 years are presented next, and this is followed by a description of observed vulnerabilities of other elements at risk. Implementation of the information outlined in the previous sections is illustrated by means of an emergency planning scenario.

1 HISTORICAL CONTEXT

There have been 54 major earthquakes in Turkey during 1903-90, causing the deaths of 70 thousand persons, and injuring 120 thousand more. More than 400 thousand houses have been destroyed or heavily damaged. Other forms of natural disasters have been ten times less effective in causing human losses; two-thirds of all material losses caused by natural disasters is due to earthquakes (Ergünay 1991).

Until the enactment in 1959 of comprehensive legal measures to mitigate natural disaster consequences, the government's response to earthquake hazard had been case-specific, and reactive in character. With the establishment that year of the Ministry of Reconstruction and Resettlement (this ministry was combined in 1984 with the Ministry of Public Works, and its current designation is the Ministry of Public Works and Settlement), and the implementation of disaster mitigation measures through the services provided by the General Directorate of Disaster Affairs have proven to be good policy decisions in disaster mitigation. Through its central and provincial offices the ministry has been able to respond to emergency requirements quickly and in an effective way.

The Disasters Law and its affiliated statutes carry stipulations on assistance to be disbursed to affected persons in the wake of natural disasters. An article of the law requires that the degree or extent of structural damage in buildings be determined by the ministry so that non-repayable grants of commensurate amounts may be made available to their owners. This legal requirement has been the principal driving force behind much of the work in Turkey towards the damageability criteria and vulnerability function development. The need is obvious. The descriptive qualification of damage in a house must be fair and unequivocal so that its owner may be allowed to recover a modest part of his losses which the law permits.

2 DAMAGE ASSESSMENT

Damage assessment is performed with the help of a survey form which has undergone several revisions. Traditionally, and for legal reasons, damage quantification is done on a global basis with the accepted designations of "slight", "moderate", and "heavy or collapsed". A substantial amount of non-technical or administrative information needs to be entered on the form so that the building, its owner(s), and its location can be identified later in a unique way. The parts with the greatest relevance for vulnerability function development are related to structural type and criteria for damage quantification. A recent survey of structural systems of low-cost rural or semi-urban dwellings (Ergünay 1990) shows that three-fourths of the housing stock is constructed of block masonry of which stone and adobe are the two most prevalent forms. The rest is either timber framed with filler walls or hybrid systems. With structural walls forming either the loadbearing system or an important part of it, it has become necessary to draw a primary correlation between damage to individual walls and overall structural damage. The secondary relationship in damage quantification is indexed to the roof structure of rural housing stock because this often occurs in conjunction with wall damage.

The reverse side of the current damage assessment form is shown in Figure 1. While the front side contains entries collected under 15 categories the reverse is designed as a combination of short and concise descriptions of information to be entered under the groupings of administrative, building typology, and damage state. Identification of a particular information component is facilitated by a combination of icon-like drawings and/or descriptions. In its basic outline the assessor must enter information for the most heavily damaged wall, regardless of at which level this wall or group of walls is located. Independent of the constitution or material used in

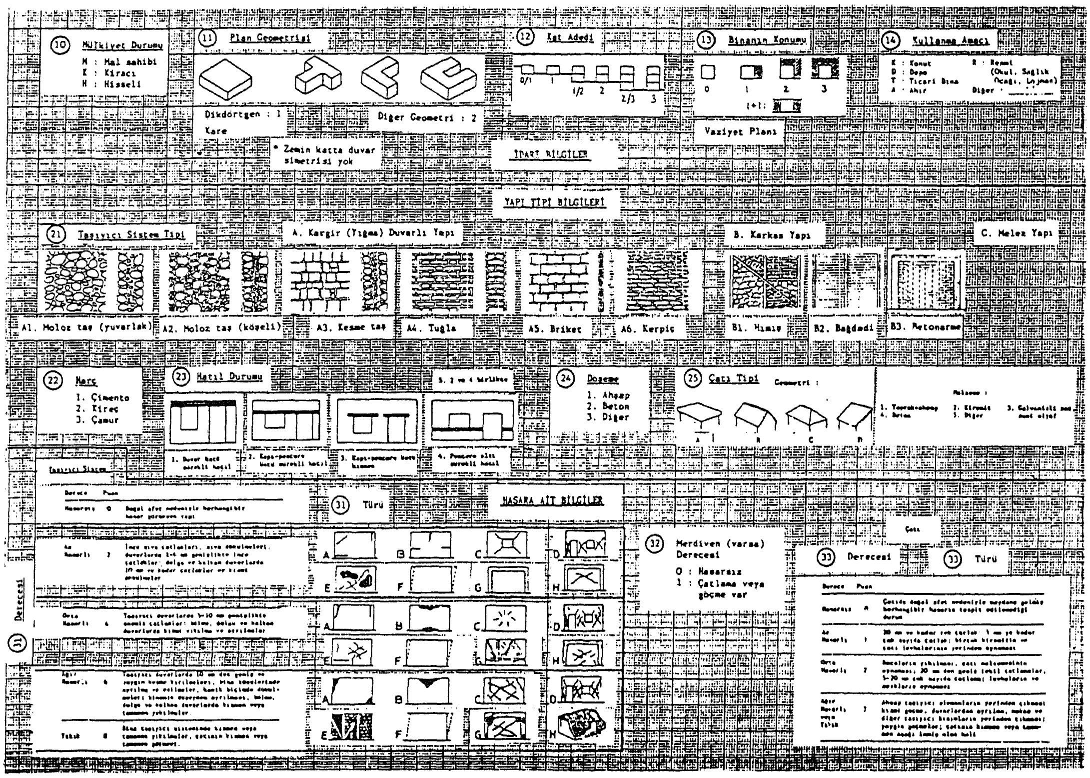


Figure 1. Damage assessment form

building the wall, a number of key points must be matched by the assessor between the form in his hand containing the mock-up damage states and the wall in front of him. While "damage state" can be an ephemeral and therefore potentially controversial entity, objective, stable and transportable descriptions must be established for consistent quantification (Gülkan 1989). A key point to remember is that the assessment must be done very rapidly by the person filling out the form. Enough rows exist on each form to accommodate data for 15 houses. Speed is essential because global sums related to the severity of the effects of an earthquake are required for organizing emergency services or post-disaster rehabilitation resources. It is unavoidable that some subtle (and involved) structural criteria will be lost when damage is described in a simplified way. It is also reasonable to assume that a few of the typically hundreds of assessors employed in the survey step will not be engineers, and therefore require easily comprehensible instructions rather than the unfamiliar professional jargon. We describe this necessary simplification next.

Plaster cracks, local spalling, structural cracks in loadbearing walls up to 4 mm wide, or up to 10 mm wide in partition walls are grouped in the form under "slight" damage, and accorded 2 points. "Medium" damage with a coefficient of 4 is identified with structural cracks up to 10 mm width, more widely distributed and widespread cracking and local crushing of structural walls. The case of "heavy" damage, credited with 6 points is when shear cracks wider than 10 mm are spread over 50 percent or more of the wall area, pyramidal portions are crushed and pushed out of the wall proper in intersecting segments, and lateral out-of-plumbness or local fall-outs from the wall or local collapses are observable. Total collapse of a structure can often be established unequivocally; the icon figure depicting that situation leaves no margin for interpretative action, and carries a point sum of 8.

Roof damage is categorized along similarly worded lines into three major groups, but deliberately accorded one-half of the corresponding points for walls so that it does not become the controlling factor. Very often, roof damage is a means by which wall damage can be confirmed; there is a strong correlation between these two items because the diaphragm function fulfilled by the roof controls the degree to which the lateral load resisting mechanism of a (block masonry) house corresponds to that of a "box" system.

Final overall damage category is assigned numerically as the sum of the wall plus roof damage as shown in Table 1.

Table 1. Numerical damage classification

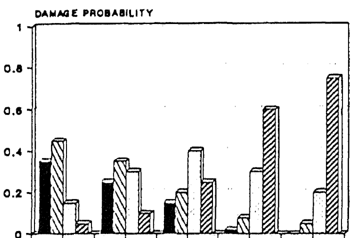
Total Points	Damage Category
0	No damage
1 - 3	Slight damage
4 - 6	Medium damage
7 or more	Heavy damage or collapse

3 VULNERABILITY FUNCTIONS FOR BUILDINGS

Losses from a hypothetical future earthquake can be estimated by establishing relationships between ground shaking intensity and the degree to which a particular type of construction will be affected and damaged. Vulnerability functions are the means by which this information can be portrayed. These functions have generally been developed by compiling statistical observations, or more rarely, by theoretical or experimental means modified by expert opinions. The last two groups have not yet reached the degree of maturity of empirical functions, and our data is exclusively of this nature. Examination of damage incurred in the prevailing structural classes, their quality of construction, correlations with site geologic conditions and measured or inferred ground motion severity are the steps with which the functions we present in this section have been developed.

We have conducted "retrofitting" types of analyses for providing a comparison between damage classification done in accordance with the form in Figure 1 and its earlier versions. Our conclusion is that damage level assessment is a stable parameter, and does not change in an appreciable way between updated survey forms. The data base reflected in the functions shown in Figures 2 - 6 contains 30'000 entries.

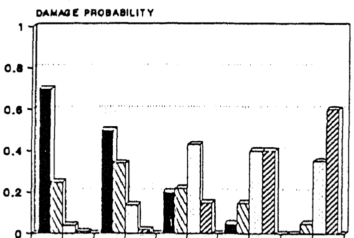
There are two ways of interpreting the information contained in this group of figures. We note that the sums entered for the given damage states and at a given intensity total unity. The number of cases from which this statistic has been drawn is large, so we may interpret the percentages as the probabilities of expected damage for that state. The same information can be converted into a set of fragility curves by means of the following reasoning. For a particular intensity and damage state the percent figure should be added to the figure of damage or damages preceding it in the same column and then subtracted from unity to determine the expected minimum damage matching that description. Taking, for illustration purposes, stone masonry and intensity VII, we note that there exists a 15 percent probability of no damage (Figure 2), and therefore an 85 percent probability of at least slight damage. The sum for no damage plus slight damage is 0.35, which tells us that there is a 65 percent probability of at least medium damage. For the description of heavy damage including collapse, this procedure is of course equivalent to simply



DAMAGE STATES	V	VI	VII	VIII	IX
NO DAMAGE	0.35	0.25	0.15	0.02	0
SLIGHT DAMAGE	0.45	0.35	0.2	0.08	0.05
MEDIUM DAMAGE	0.15	0.3	0.4	0.3	0.2
HEAVY DAM.+COLLAPSE	0.05	0.1	0.25	0.6	0.75

MSK INTENSITIES

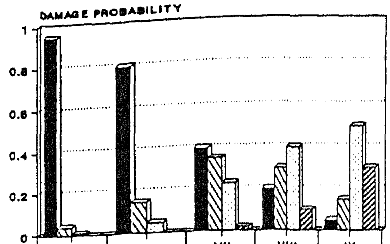
Figure 2. Damageability for stone masonry structures



DAMAGE STATES	V	VI	VII	VIII	IX
NO DAMAGE	0.7	0.5	0.2	0.05	0
SLIGHT DAMAGE	0.25	0.34	0.22	0.15	0.05
MEDIUM DAMAGE	0.04	0.14	0.43	0.4	0.35
HEAVY DAM.+COLLAPSE	0.01	0.02	0.15	0.4	0.6

MSK INTENSITIES

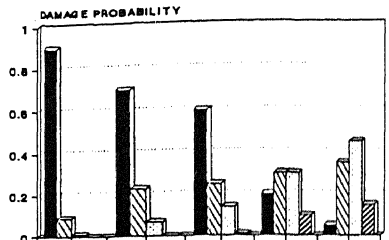
Figure 3. Damageability for adobe masonry structures



DAMAGE STATES	V	VI	VII	VIII	IX
NO DAMAGE	0.95	0.8	0.4	0.2	0.05
SLIGHT DAMAGE	0.04	0.15	0.35	0.3	0.15
MEDIUM DAMAGE	0.01	0.05	0.23	0.4	0.5
HEAVY DAM.+COLLAPSE	0	0	0.02	0.1	0.3

MSK INTENSITIES

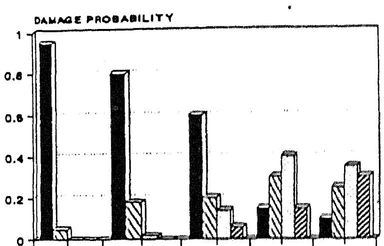
Figure 4. Damageability for brick masonry structures



DAMAGE STATES	V	VI	VII	VIII	IX
NO DAMAGE	0.9	0.7	0.6	0.2	0.05
SLIGHT DAMAGE	0.09	0.23	0.25	0.3	0.35
MEDIUM DAMAGE	0.01	0.07	0.14	0.3	0.45
HEAVY DAM.+COLLAPSE	0	0	0.01	0.1	0.15

MSK INTENSITIES

Figure 5. Damageability for wood-frame structures



DAMAGE STATES	V	VI	VII	VIII	IX
NO DAMAGE	0.95	0.8	0.6	0.15	0.1
SLIGHT DAMAGE	0.05	0.18	0.2	0.3	0.25
MEDIUM DAMAGE	0	0.02	0.14	0.4	0.35
HEAVY DAM.+COLLAPSE	0	0	0.06	0.15	0.3

MSK INTENSITIES

Figure 6. Damageability for reinforced concrete structures

plotting the complementary percentages across that row. A figure prepared in accordance with this procedure is given in Figure 7.

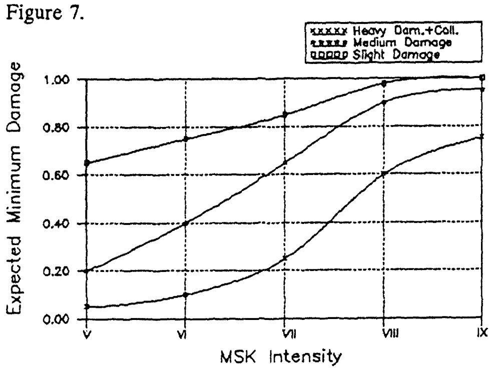


Figure 7. Fragility curves for stone masonry structures

4 VULNERABILITY OF OTHER ELEMENTS AT RISK

With the exception of the 1967 Adapazarı, 1971 Burdur, and 1976 Denizli events all major earthquakes in Turkey have affected rural or semi-rural areas, leading to a paucity of damageability data on urban infrastructure components. In weak alluvial soil formations 1 rupture per km has been reported for buried utility lines for intensity IX. In urban power distribution or telephone networks, interruption of service occurs in 25 percent of the system for intensity IX, 15 percent for intensity VIII, and 5 percent for intensity VII.

Examination of statistics on loss of life and injuries reveals that there are differences in figures for the same intensities between different regions because of varying building practices, workmanship and qualities. The fatality ratio, defined as deaths/collapsed buildings is given in Table 2.

Table 2. Fatality ratio

	MSK Intensity			
Building Type	VI	VII	VIII	IX
Stone masonry	0.002	0.008	0.080	0.130
Adobe masonry	0.002	0.008	0.080	0.130
Brick masonry	0	0.001	0.010	0.050
Wood framed	0	0	0.003	0.020
Reinforced concrete	0	0	0.002	0.010

Empirical relations have been developed between fatalities (D) and the number of heavily damaged or collapsed buildings (N) as follows:

$$D = C\,N^{1.32} \qquad (1)$$

In Eq.(1) the coefficient C depends on the building type as follows:

Type	C
Reinforced concrete	0.003
Wood framed	0.005
Brick masonry	0.008
Stone/adobe masonry	0.010

The fatality/injury ratios which we give in Table 3 show greater variability between regions with different climates, building practices, and/or vernacular properties. When the data is divided into "east" and "west" parts, statistics yield the entries in the table.

Table 3. Fatality/Injury ratios

	MSK Intensity			
Region	VI	VII	VIII	IX
East	0.23	0.26	1.32	4.67
West	0.10	0.09	0.30	0.49

This table shows that in large earthquakes injuries in the eastern parts of the country are fewer than deaths. This may be explained in terms of the heavy earthen roofs most rubble stone masonry houses support. The figures reveal that buried victims have little chance of being rescued from underneath the heaps of soil, and that minor injuries may not be reported to the medical corps.

5 A CASE STUDY

A comprehensive risk study fusing together many of the elements to which we have alluded above was performed for the province of Bursa (Coburn 1985, Ergünay 1990). This study considered the general levels of damage which would be anticipated to occur in the province following different magnitude earthquakes. Of course, such disasters are known to be sporadic, and extremely variable in their characteristics and consequences. The study relied heavily on the type of observed behavior noted in Figures 2 - 7 and Tables 2 - 3 with some local adjustments. It consisted of three parts:

a) Hazard study
b) Vulnerability study
c) Analysis and disaster scenario

For purposes of identifying places most at risk, the map of maximum probable intensity across the province was combined with the population map and the building type distribution map to give the number of houses which would be damaged in each place if the corresponding intensity were to be experienced there.

In order to estimate the level of emergency planning which may be necessary, the scenario of the hypothetical earthquake occurring somewhere in the province had to be evaluated. The imaginary damage pattern based on known intensity attenuation relationship for a magnitude 7.2 earthquake located in a possible location determined from the hazard study. The total damage expected from this event is summarized in Table 4.

Table 4. Expected losses from hypothetical earthquake

	Number of houses with damage category		
	Moderate	Heavy	Collapse
Villages	34 000	15 000	4 000
Municip.	21 000	9 000	2 000
Bursa	50 000	30 000	6 000
	Number of people		
	Killed	Injured	Homeless
Villages	2 000	6 000	73 000
Municip.	800	2 500	36 000
Bursa	1 500	4 500	130 000

There is reason to believe that the figures quoted in Table 4 are at the upper end of the expected ranges of possible levels. The largest uncertainty can be attached to estimates of human casualties, but for planning purposes casualty rates comparable to the Gediz earthquake of 1970 could probably be justified. For emergency plans the number of houses made uninhabitable and the number of people killed is an indication of the relief and rescue needs within the immediate aftermath of the disaster. Injuries are an indication of the medical facilities needed, and the number of people left homeless determines the level of need for temporary shelter, initially for tents and rapidly erected facilities, and for more substantial housing over the longer haul.

6 CONCLUSIONS

Quantitative observations of damage caused by past earthquakes on different classes of houses and other forms of losses in Turkey have yielded a large body of data from which statistical tools may be devised for loss estimation studies and emergency plan requirements. This paper has presented vulnerability functions in the form of bar charts for the housing stock. The damage assessment form shown in Figure 1 is a step toward the development of stable and transportable devices with which disaster scenarios may be constructed with greater confidence.

REFERENCES

Coburn, A.W. & U. Kuran (Eds.) 1985. Emergency planning and earthquake damage reduction for Bursa province: A preliminary evaluation of seismic risk. Earthquake Research Department of the Turkish Ministry of Public Works and Housing and The Martin Centre for Architectural and Urban Studies, University of Cambridge, U.K., December.

Ergünay, O. & P. Gülkan 1990. Earthquake vulnerability, loss and risk assessment. Proc. Workshop II, UNDP/OPS/UNDRO Cooperative Project for Seismic Risk Reduction in the Mediterranean (SEISMED), Trieste, Italy, December.

Ergünay, O. & P. Gülkan 1991. Seismic risk reduction and disaster management. Proc. Workshop III UNDP/OPS/UNDRO Cooperative Project for Seismic Risk Reduction in the Mediterranean (SEISMED), Rome, Italy, November.

Gülkan, P. & H. Sucuoğlu 1989. Assessment of earthquake damage in rural buildings. Earthquake Engineering Research Center Report No. 89-02, Middle East Technical University, Ankara, Turkey, December.