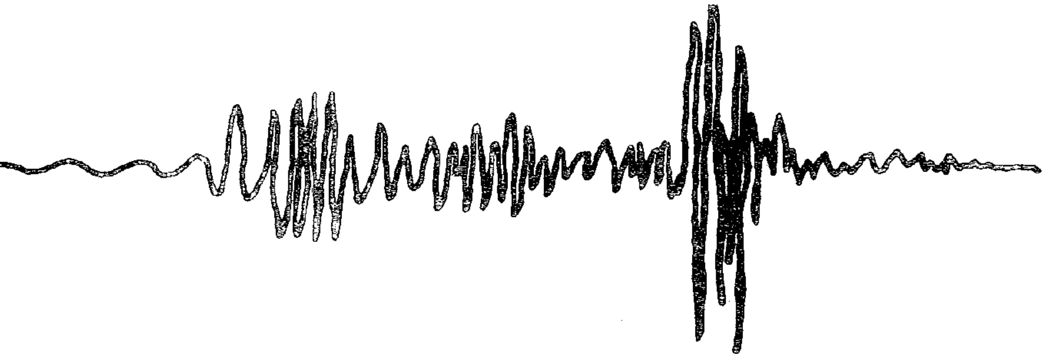
Destructive Earthquakes in



Burdur and Bingöl, Turkey

MAY 1971

NATIONAL ACADEMY OF SCIENCES

DESTRUCTIVE EARTHQUAKES IN BURDUR AND BINGÖL, TURKEY - MAY 1971

report and recommendations
by

W. O. Keightley
Montana State University

submitted to the

Committee on Natural Disasters
NATIONAL RESEARCH COUNCIL

National Academy of Sciences
Washington, D.C.

1975

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FOREWORD

One of the activities of the Committee on Natural Disasters, National Academy of Sciences-National Academy of Engineering, is to assemble, prepare, and publish various types of reports on the effect of major earthquakes on engineered structures. The objective is to document the extent and nature of the ground tremors and the damage sustained in order to build up a body of earthquake engineering information that may be helpful in developing improved technological methods for earthquake resistance.

At the time of the Burdur and Bingöl earthquakes in southwestern Turkey in 1971, Dr. W. O. Keightley was in residence at the Middle East Technical University at Ankara. Accordingly, the Committee asked Dr. Keightley to visit the sites and submit a descriptive report of the event and its consequences.

Structures and urban conditions in Turkish towns in the interior of the country are, of course, quite different from those in the United States. However, sizable portions of some U.S. cities consist of old buildings, not designed to resist earthquakes and not so dissimilar from corresponding buildings in Turkish towns. Therefore, the effects of the Burdur and Bingöl earthquakes, described in Dr. Keightley's report to the Committee, may provide lessons of value to some U.S. cities.

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Several photographs were supplied by Professor Asim Yeğinobali, Department of Civil Engineering, Middle East Technical University, and credit is noted in the caption in each instance. Other illustrations from reports of the Government of Turkey and the California Institute of Technology and from Tectonophysics and the Bulletin of the Seismological Society of America are gratefully acknowledged. Thanks are due to the photo lab personnel of the Hydraulics Laboratory of the Middle East Technical University for processing the films and to stenographers in the Department of Civil Engineering and Engineering Mechanics, Montana State University, for typing the report.

At the time of these investigations, the author was a visiting professor in the Department of Civil Engineering, Middle East Technical University, Ankara, Turkey. He is grateful for the cooperation of the department and the university.

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I.

INTRODUCTION

At 8:25:13 a.m. local time (06:25:13 GMT), May 12, 1971, an earthquake reported in the Richter Magnitude range 5.5-6.3 struck the area of Burdur, a modern city of 33,000 people in southwestern Turkey. Fifty-seven persons were killed, and property damage estimated at $25 million resulted.* Just ten days later, at 6:43:59 p.m. local time (16:43:59 GMT), another earthquake, reported in the Magnitude range 6.0-6.9, struck the area of Bingöl, a city of 17,000 population, 900 km ENE of Burdur. Here 755 persons were killed, and property damage was estimated at $28 million.* These earthquakes, together with the Gediz earthquake (March 28, 1970, Magnitude 7.0-7.5) (References 7,8,9), in the span of a little more than one year, killed some 1,900 persons in this nation of 35.6 million, and cost in damages and relief efforts at least 5% of the annual national government budget of some $2 billion.

Almost all of this loss of life and property occurred when man-made structures collapsed or were damaged by strong ground shaking. Had the buildings been constructed more resistant to earthquakes, at admittedly some increase in cost, there could have been very few deaths, greatly reduced property damage, and very little disruption of normal living.

It is the purpose of earthquake engineering to supply technical knowledge and advice which can reduce the loss of life and property in seismically active areas, as in much of Turkey. This report, sponsored by the U.S. National Academy of Engineering, is intended to contribute to this endeavor by presenting observations and analyses of earthquake damage in Turkey, and by making recommendations for structural improvements and for better dissemination and enforcement of building design and construction regulations.

Following this Introduction, there are short discussions of the seismic risk in Turkey, construction practices, prices of building materials, and building regulations. The remainder of the report presents photographs and descriptions of the earthquake damage.

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*The cost of reconstruction

II.

THE SEISMIC RISK IN TURKEY

Assuming that tectonic processes active in the recent past will continue in the future, the best evidence of seismic risk at a particular place is the record of past earthquakes in the nearby area, together with a knowledge of local geologic features associated with crustal movements. There are strong reasons to assume that areas which have experienced earthquakes in the past will experience them in the future, and it can be postulated that certain areas which have had no known strong shaking in the past will be strongly shaken in the future, by virtue of their locations relative to recognized faults, lines of epicenters, etc. Much of Turkey has a history of destructive seismic activity, going back to the earliest days of recorded history. In recent times one earthquake of Richter Magnitude 6 or greater each year, on the average, has occurred in Turkey (area 300,000 square miles). Inasmuch as most of Turkey's population of 35 million is housed in buildings which are heavy, brittle, and weak, the seismic risk in Turkey can be said to be high.

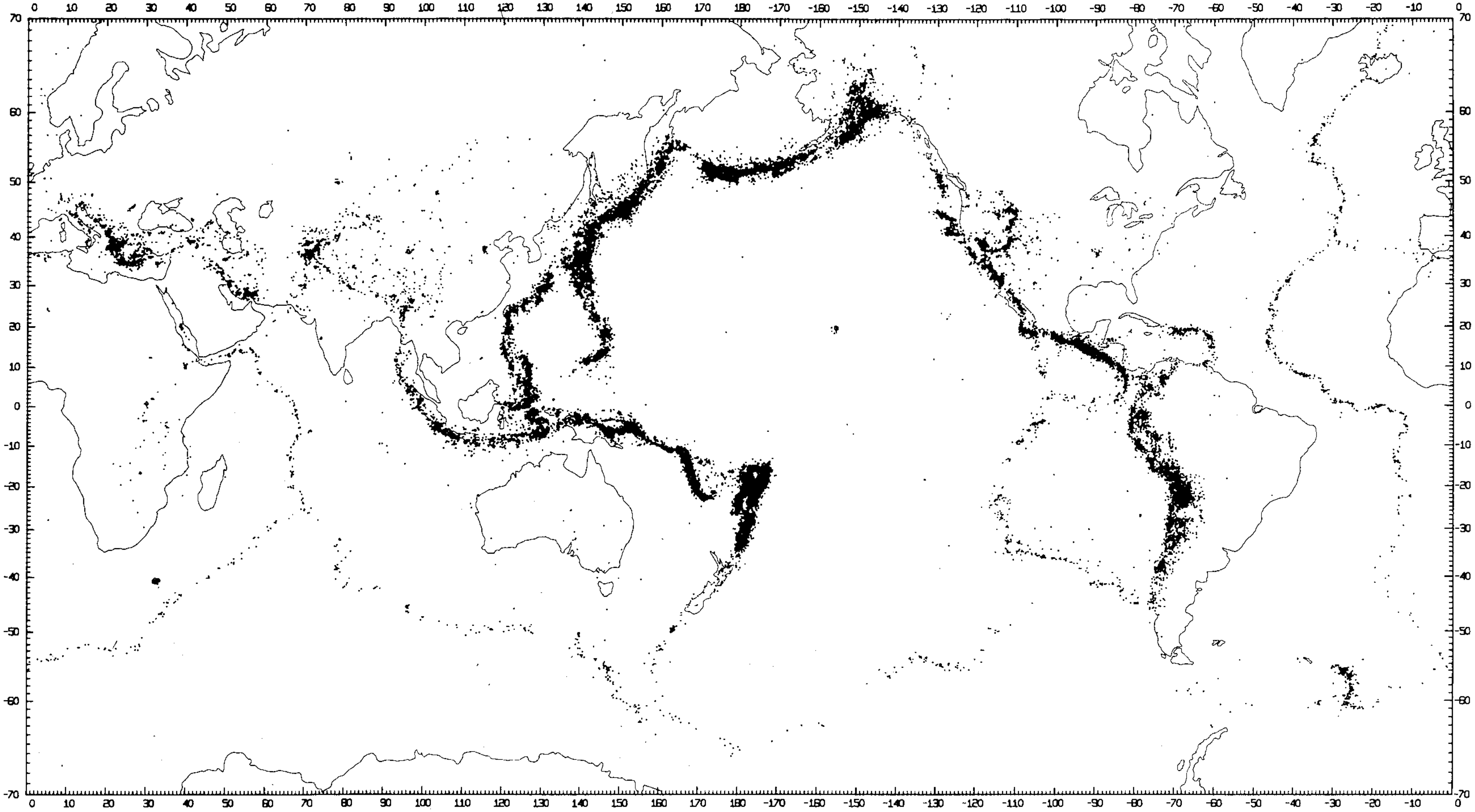
Turkey's location in the pattern of worldwide seismicity is shown in Figure 1 (Reference 1), which depicts epicenters of earthquakes of Magnitude 4 and greater in the years 1961-67. Turkey is in the Alpide Belt of seismicity which runs from the East Indies, through northern India, Afghanistan, Iran, Turkey, Greece, Yugoslavia, and Italy, into the Swiss Alps. The line of epicenters extends from the Alps further west, through Spain, to connect with the line on the mid-Atlantic ridge. The heaviest concentration of epicenters southeast of the Italian boot is in Greece and in the Aegean and Mediterranean Seas, not actually within the borders of Turkey.

A closer look at the distribution of Turkey's earthquakes is given in Figure 2, prepared by Professors Kasim Ergin, Uğur Güçlü, and Göknur Aksay of the Department of Geophysics, Istanbul Technical University (Reference 2). The authors have plotted instrumentally-determined epicenters from recent years, and have also used historical accounts to estimate magnitudes and epicentral locations of earthquakes occurring as early as 11 A.D. Historical earthquake data are presented in a different way in Figure 3 by Ambraseys (Reference 3), in which are shown ancient cities in Asia Minor and part of the Middle East destroyed by earthquakes in the period 10-1000 A.D. The larger the dot in Figure 3, the more times a city was affected by destructive earthquakes, the largest representing four or more devastations due to earthquakes. Naturally, data obtained from the destruction of ancient cities is geographically biased toward areas of settlement, often along coasts, trade routes, and fertile valleys, but nevertheless it is fact, not supposition, and it extends the observation interval of instrumental records, at least in the area of continuously occupied cities, by factors as large as 25.

Examination of Figure 2 shows two fairly well defined lines of epicenters crossing at about a 45° angle at roughly 39°N, 41°E. The line of epicenters that traverses west to east through northern Turkey, then curves to the southeast toward Lake Van, is associated with the North Anatolian fault. Some recent movements on this fault are shown in Figure 4 (taken from Reference 3). The fault, which exhibits right lateral strike, is well defined over a length of 900 km (Reference 4). The intersecting line of epicenters, running NE-SW and perhaps slightly offset in a left lateral strike sense by the North Anatolian fault, is not associated with any such outstanding feature, at least so far identified, but it was along this line that the Bingöl earthquake reported herein occurred. Allen (Reference 4) suggests that faults parallel to this line of epicenters might be associated with the Dead Sea fault system, which is left lateral strike (Figure 5). It is interesting to note (Figure 3) that along the Dead Sea fault, in present Syria, Lebanon, and Israel, many ancient cities were destroyed, but most of this area was free of earthquakes in the period 1961-67, as shown in Figure 1. Earthquakes close to the intersection of the two lines of epicenters at 39°N, 41°E claimed many lives in recent years -- an estimated 30,000 or so in Erzincan in 1939, 2,300 in Varto in 1966, and 785 in Bingöl in 1971.

In southwestern Turkey, the location of Burdur, the distribution of most earthquakes does not follow such well-defined lines. The presence of numerous lakes of high mineral content in this area, without surface outlets, suggests that uplifting is going on, resulting in earthquakes associated with graben faulting, among other types of block movements.

To help inhabitants protect themselves against earthquakes, the Turkish government has prepared earthquake zone maps and issued building regulations for earthquake-resistant construction. Figure 6 shows the zone map adopted in 1963 and still in use in 1971. On this map darker colors indicate greater assumed earthquake risk, white designating an area of negligible risk. The long black zone across the top of Turkey, 1st degree risk, straddles the North Anatolian fault, whereas the line of epicenters associated with the Bingöl earthquake is rated 2nd degree to the southwest of the North Anatolian fault, and 1st degree northeast of it. Burdur, which is alongside the southern-most of two long narrow lakes in southwest Turkey, is shown to be in a zone of 1st degree risk. The newest risk zone map, not yet officially adopted in 1971, appears in Figure 7. This map, which shows four degrees of risk plus a zone of negligible risk, assigns some risk to more than 90% of the area of Turkey.



SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS
DEPTHS 000-700 KM.

FIGURE 1 (From Barazangi and Dorman, Reference 1.)

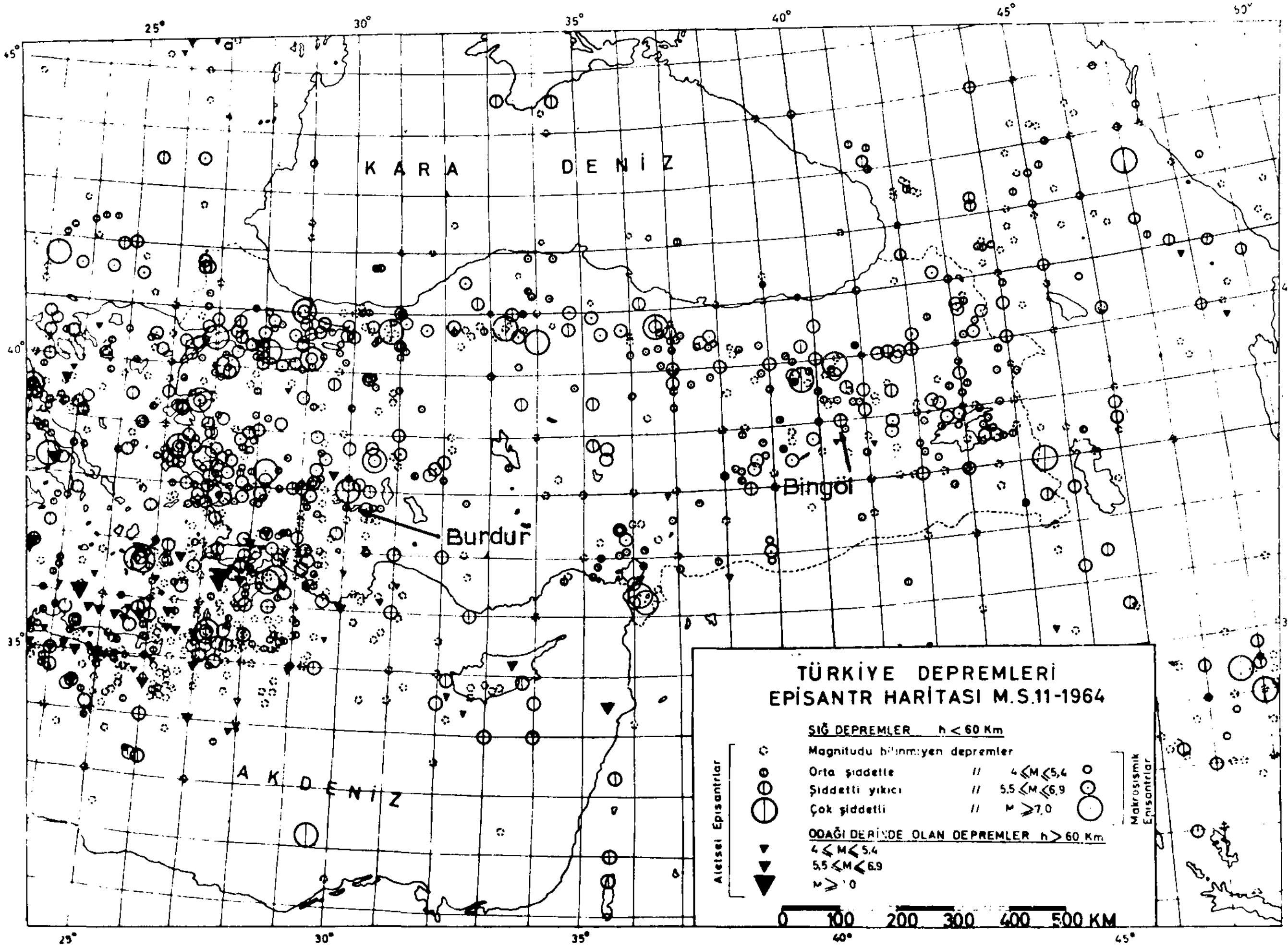


FIGURE 2 (From Ergin et al., Reference 2.) Earthquakes in Turkey and the surrounding area in the period 11-1964 A.D. Historical accounts have been used to locate and scale earthquakes occurring before the early part of this century.

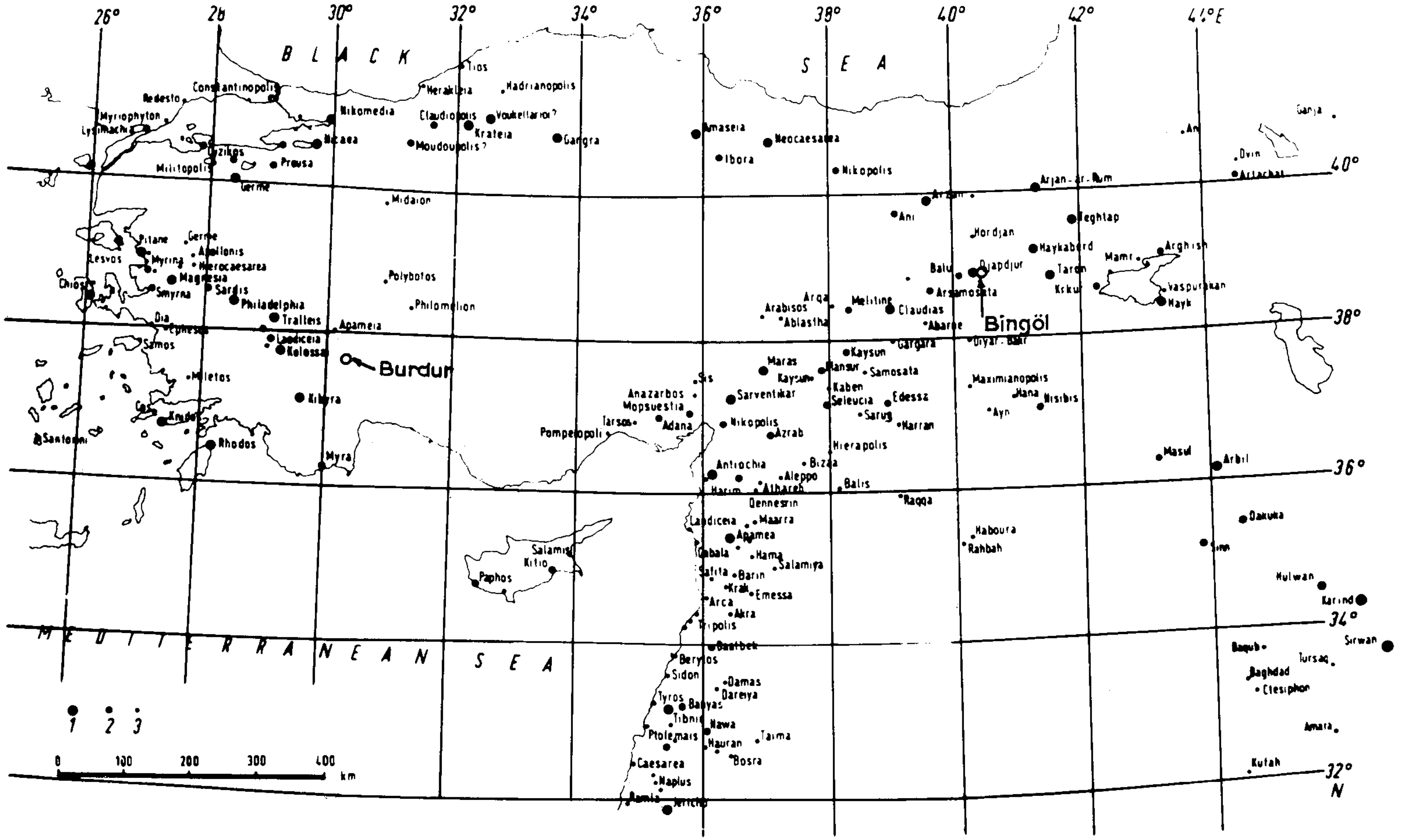


FIGURE 3 (From Ambraseys, Reference 3.) Earthquakes in Turkey and the eastern Mediterranean region in the period 10-1000 A.D. Largest circles - sites destroyed by earthquakes at least four times, causing serious damage and widespread concern. Medium size circles - sites destroyed less than four times, but more than once. Smallest circles - sites destroyed or affected by strong earthquakes.

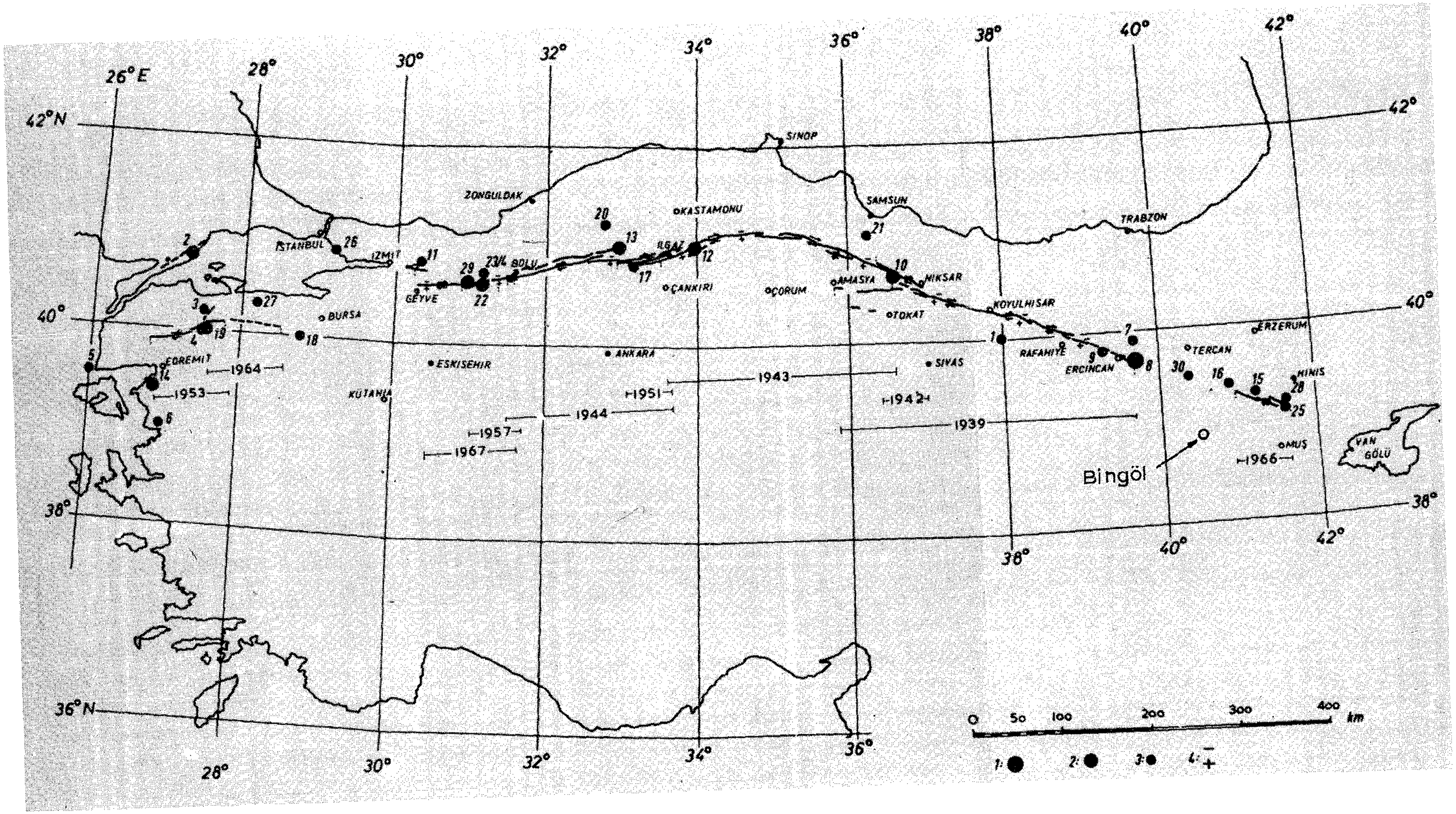


FIGURE 4 (From Ambraseys, Reference 3.) Sequence of faulting of the North Anatolian fault in the period 1939-1967.

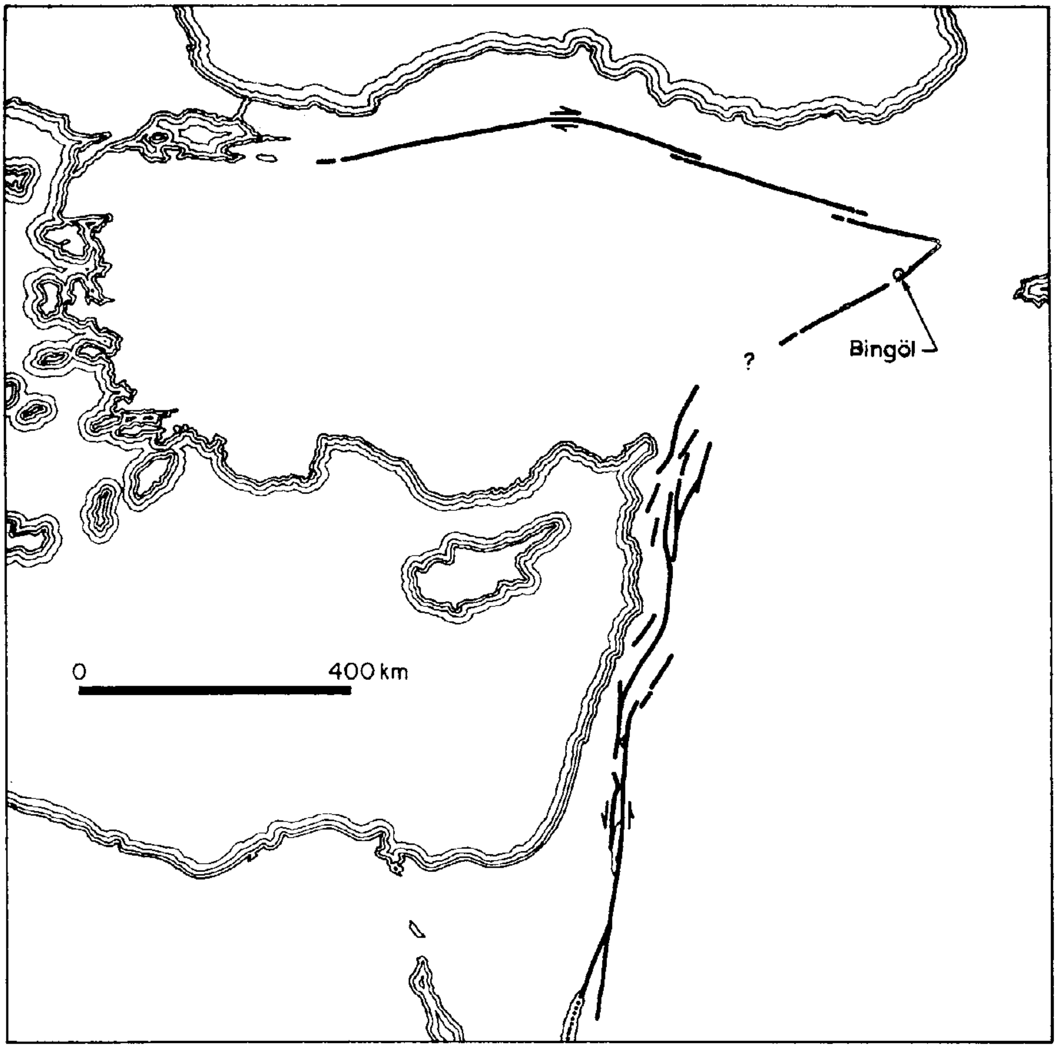


FIGURE 5 (From Allen, Reference 4.) Showing the North Anatolian fault (right lateral strike) and the Dead Sea fault system (left lateral strike).

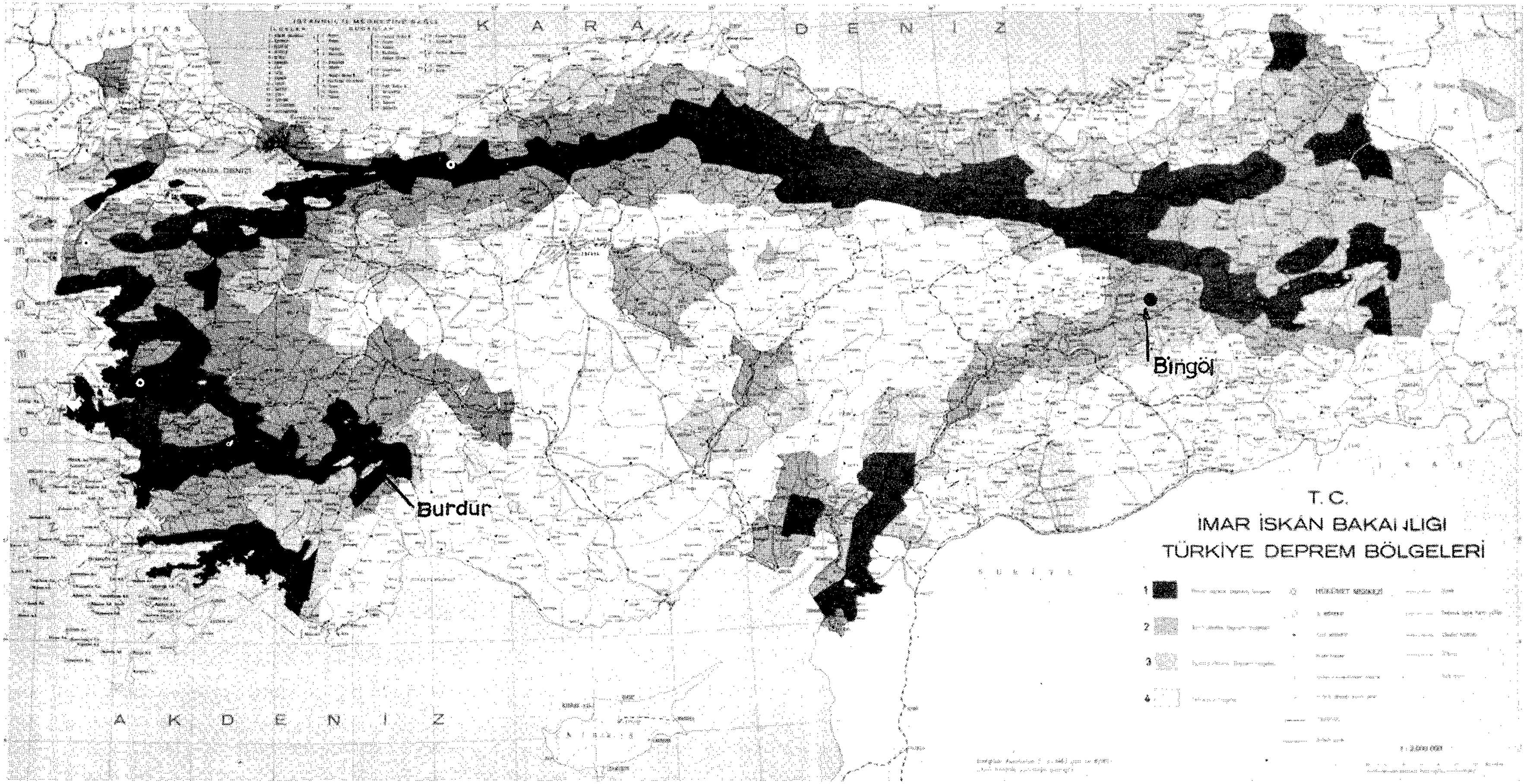


FIGURE 6 Earthquake risk zone map of Turkey, adopted in 1963 and still in use in 1971. The darker the color, the greater the risk. White indicates areas in which no precautions are required against earthquakes in building construction.

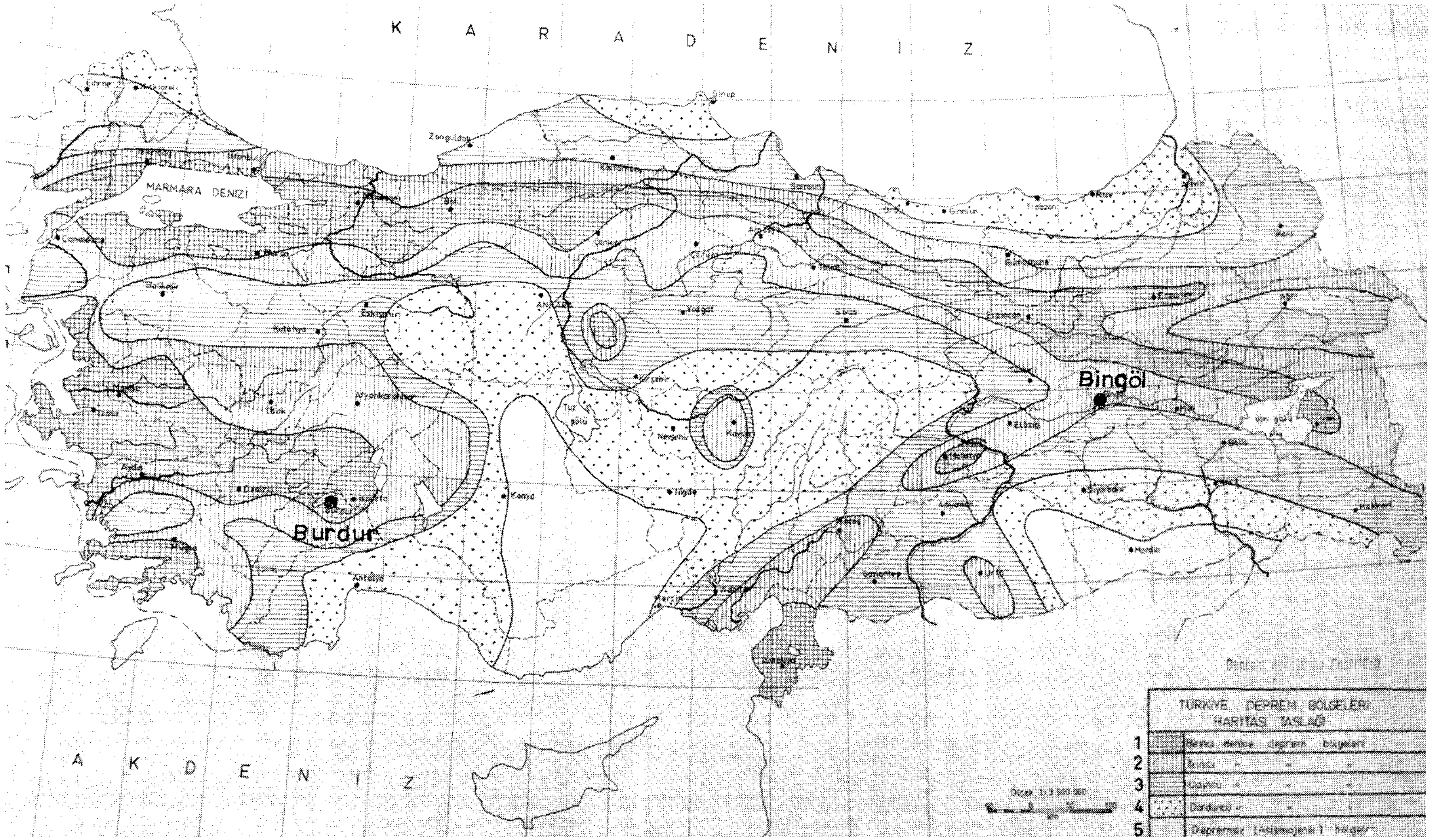


FIGURE 7 Proposed earthquake risk zone map for Turkey, not yet adopted as of 1971. The smaller the number, the greater the risk.

III.

HOUSE CONSTRUCTION PRACTICES IN TURKISH VILLAGES*

A collection of houses sheltering fewer than 2,000 people in Turkey is called a village. It is estimated that 60% of the population or 21,000,000 persons live in villages, of which there are some 36,000 in the country. The villages are surprisingly uniformly distributed over the countryside because most of the land is farmed or grazed. The farms are small (14 acres average), and there is very little personal motor transportation (one private vehicle for every 200 citizens, most in the cities). Therefore, people in the country are numerous, and they live close to their farms, customarily in villages spaced every few miles rather than in isolated rural houses. When population is distributed in this way a strong earthquake will often affect at least one village.

Village houses are usually constructed by the owners, without the aid of professional builders. Most materials are obtained locally: mud and straw for adobe bricks, mud mortar and mud plaster, natural or hand-hewn logs, nails, stone which is usually unworked, sometimes baked clay roof tile or corrugated sheet steel roofing, and rarely concrete blocks, manufactured bricks, lime or Portland cement. Masonry laid in Portland cement mortar can be found in wealthier villages and sawed lumber is used in villages which are near timber and near or have electric service. The type of house construction varies from district to district, and even among closely-spaced villages within one district, depending on the availability of materials, village customs, and on the interest, knowledge, and authority of local leaders. Within individual villages the quality of construction varies with the skill, wealth, energy, and knowledge of the owner.

In the Burdur region, in southwestern Turkey, the walls of most village houses are made of adobe, usually 60 to 80 cm thick, and two stories high. Some houses contain braced frames of hand-hewn timbers built into the walls, others use wood in the walls only to frame window and door openings, and as bearings under heavy roof timbers. Many roofs in this region are of tile, but many also are flat mud roofs, sometimes

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*Village structures are shown in the figures at the end of the report beginning with Figure 15.

as much as 40 cm thick, laid on leaves or twigs, which in turn rest on several layers of branches and poles successively laid at right angles, all supported by beams of heavy poplar tree trunks. The flat mud roofs provide good insulation, are water-tight, and serve as a convenient platform for the storage of hay away from animals. Such a roof might easily weigh 750 kg/m^2, whereas a tile roof, including an insulated ceiling below, would weigh less than 1/8 as much. The collapse of heavy, weak mud walls, especially when overlaid by heavy roofs, resulted in many casualties in a few villages in the Burdur region.

In the area of Bingöl, in eastern Turkey, the walls of most village houses are made of broken pieces of basalt set in mud mortar, often with small stones keyed in between larger ones. In houses built along the rivers, cobbles are often used instead of broken stone. In this region, horizontal wood bond strips, about 10 cm in diameter and spaced 60 to 100 cm apart vertically, have been built into almost every wall. These strips are set apart horizontally by short wood pieces so that there is one strip in each face of the wall at each level (walls are usually 50 to 60 cm thick). The bond strips in one wall are usually nailed to those in an intersecting wall, and are usually nailed at joints along the length of a strip. The nailed joints are weak, however, and the strips themselves often contain deep transverse saw cuts to permit straightening, so the tensile strength of the strips is low.

The functions of the bond strips would seem to be to break up long diagonal cracks in a wall, to act as tensile reinforcement when a wall bends in the horizontal plane, and to help tie walls together at a corner. It is difficult to estimate the effectiveness of construction with bond strips, the origin of which is unknown to the author, without tests performed on a shaking table. Certainly in the Bingöl region many stone houses containing bond strips collapsed. Corners of houses fell out, joints between bond strips at the wall corners pulled apart, and walls collapsed, particularly walls parallel to roof beams, not tied together across the structure. Mud mortar in the Bingöl region was ineffective on the heavy stones except for initial dead-load compression so that there was almost no tensile strength in the walls and very little shear strength. It is believed that failure of most of these walls took place by successive collapses from the top.

It seems likely that for many years to come most Turkish villagers will continue to hand-build their own houses using minimally-processed and locally-available soil, stone, and timber. In view of the many people in rural regions, it would seem worthwhile to develop improvements in the earthquake resistance of rural houses that can be afforded and constructed by the people themselves.

IV.

CONSTRUCTION IN THE URBAN AREAS OF TURKEY

In Turkey's urban areas most existing structures are of wall bearing masonry, from one to three stories high. Many of the older buildings are made of adobe, sometimes incorporating wood bracing, or of braced wood frames with bricks used as an infill between the wood members, or of braced wood frames covered with wood lath and plaster. Most buildings being built today are of wall bearing masonry, with reinforced concrete floor slabs. However, a great many reinforced concrete frames also are being built, four stories or more in height. In the larger cities the trend in housing is definitely toward high-rise reinforced concrete frame apartment buildings, with weak masonry enclosure and partition walls. Structural steel frames and steel reinforced masonry are practically nowhere to be seen.

Inadequate workmanship, especially in reinforced concrete construction, is very common. Some examples are shown in the figures which follow. Field inspection of the structural details and quality of work during construction by the designer or by a building official is often omitted entirely. In Burdur, for instance (population 33,000), an owner hires an engineer or an architect (of which there are four and one, respectively, in the city) to prepare plans. Regulations established by the Ministry of Reconstruction and Resettlement are in effect in Burdur. When building plans have been approved by the City Engineer, the owner, usually acting as his own contractor, buys the building material and hires workmen. Construction then proceeds, with inspection by Burdur's Building Technician to verify that the dimensions of the building, number of stories, placement of stairways, etc., agree with the plans. Verification of the quality of materials, or the placement of reinforcement steel occurs only if the owner pays the designer to perform inspections.

The weaknesses, perhaps fatal in an earthquake, are that the technical details of construction are left to workmen hired off the street and to the owner, both of whom are probably ignorant of many aspects of construction. The owner, of course, is personally interested in keeping costs at a minimum. The result is often, but by no means always, undersized members of hand-mixed concrete, full of voids and segregated aggregate, with inadequate or improperly placed reinforcement, or brickwork poorly laid in mortar that is mostly lime and sand. Plaster hides these weaknesses until they are exposed by an earthquake.

V.

CONSTRUCTION MATERIAL PRICES IN TURKEY

Although the trend in large cities is toward multi-story reinforced concrete frame buildings, most structures being built in Turkey today are of wall bearing masonry or adobe, from one to three stories high, a large fraction of which are bonded with mud or lime mortar. The need for the use of more Portland cement, steel, and lumber in construction is great, yet the need exists not because these materials are scarce or higher priced in Turkey than elsewhere, but because the income of the majority of the population is so low in comparison to the material prices.

Of Turkey's 300,000 square miles (twice the area of Montana), about 24% is classified as forest, but only little more than half of this yields commercial timber, the remainder providing only fuel and grazing. The present annual growth rate is 9 to 10 million cubic meters of sawed lumber, yet Turkey saws only 60% or so of this potential, due in large part to lack of market at the asking price for lumber, which presumably reflects the production and transportation costs. Nevertheless, reforestation is going on at the rate of some 100 square miles and 300 million newly planted trees per year, and experiments are under way with hybrid poplars which grow several times as fast as ordinary poplars, and when harvested at 15 years age are worth up to $30 each at the mill.

In Burdur, not far from timber sources in southern Turkey, sawed lumber in structural lengths costs about $67 per cubic meter, or 16¢ per board foot, roughly the same as in the USA. In areas distant from forests, lumber prices are twice or more the price in Burdur.

Turkey manufactures its own cement and reinforcing steel, producing seven million tons of cement in 1970. (The United States, with six times the population, produced 75 million tons in 1971.) Cement in the Burdur region costs 87¢ per 50 kg sack, about one half the price in the United States, and reinforcing steel costs about 21¢ per kg, roughly the same as in this country. On the other hand, common bricks, made to a large extent by hand labor in Turkey, cost one cent each and up, depending on the length of haul. United States prices are in the range of four to six cents each. Hollow concrete blocks cost five to seven cents each, whereas in this country they cost 30 to 40 cents each.

A major obstacle to incorporating more wood, steel and cement into construction is that these materials are relatively expensive in Turkey. The average annual income in Turkey is only $200 to $250 per person. Labor, on the other hand, is cheap -- $1.75 per day, more or less, for common labor; therefore, most construction is made of masonry, and often with as little cement as possible.

Substantial improvement in the overall economic situation in Turkey, which would lower the price of earthquake-resistant construction, is anticipated (lately the gross national product has been increasing at six to seven percent per year, population at two and six tenths percent per year), but it will not be accomplished in only a few years. A recommendation for use of locally grown and sawed timber in village construction during the interim is given later in this report.

VI.

BUILDING REGULATIONS IN SEISMIC ZONES OF TURKEY

Building construction in the seismic zones of Turkey is subject to regulations published by the Ministry of Reconstruction and Resettlement (Imar ve Iskan Bakanliği). This ministry was empowered by Law No. 7269, as amended in 1968, to prepare an earthquake zone map of the country, to establish institutes to study measures for protection against natural disasters (primarily earthquakes, landslides, and floods), to analyze the effects of disasters, to publish and distribute information, and to prepare, in conjunction with the Ministry of Public Works (Bayindirlik Bakanliği), regulations to control construction in the approximately 60% of Turkey's area which has so far been designated as subject to significant seismic risk.

Under the direction of a minister appointed by the Prime Minister, the Ministry of Reconstruction and Resettlement consists of a General Directorate of Planning and Reconstruction, which approves city plans, does regional planning, and plans the activities of the ministry; a General Directorate of Building Materials, which conducts research on materials and gives technical advice and financial credit to materials producers; a General Directorate of Housing, which builds low cost housing, rehabilitates slums, expropriates land for new housing areas, does research on housing types, and gives credit and advice to home builders; a General Directorate of Natural Disaster Affairs, which gives assistance to people affected by earthquakes, landslides, and floods; a General Directorate of Technical Affairs of Municipalities, which is concerned chiefly with utilities; a Real Estate Credit Bank and a Provincial Bank, which loan money to help carry out the programs of the Ministry; and the Earthquake Research Institute, which conducts research related to earthquakes and earthquake damage, prepares the earthquake zone map, and now has responsibility for revising building regulations used in designated earthquake zones.

In 1971 the Earthquake Research Institute consisted of five Civil Engineers, three Geologists, five Geophysicists, an Electrical Engineer, a Physicist, and several technicians and clerical workers, making a total of about 35 persons. At present, the Institute is engaged in preparing a new seismic zone map, in preparing reports on earthquake damage, in studying areas for relocation of villages, in revising building regulations for seismic zones, and in acquiring strong motion accelerometers and other instrumentation. At present there are only six or eight strong motion accelerometers in Turkey, most located in dams under construction.

The law which gave the Ministry authority to prepare building regulations stipulated that regulations were to be reinforced at the province level or below. Turkey is divided into 67 provinces, which are further divided into some 571 areas called towns. Within the towns are municipalities, which are urban centers of population 2,000 or more, and smaller urban centers, called villages. There are approximately 1,500 municipalities and 36,000 villages in Turkey. Each province is headed by a governor (Vali) appointed by the Prime Minister, through the Ministry of Interior, and each town is headed by a town governor (Kaymakan) similarly appointed. In the municipalities mayors are elected, and in each village a head man (Muhtar) is elected.

Municipalities usually regulate construction within their boundaries through building officials appointed by the mayors, but it is estimated that at least half of the municipalities actually have no technically trained persons on the payroll. In theory town governors control construction in the villages, but in most cases without the aid of professional help. There is no law that requires the employment of a building engineer by a town or a municipality, and Law 7269 prescribes no penalties for failure to observe the building regulations. The Ministry has representatives in most of the provinces, but these men are usually assigned to the construction of special projects, such as relocated villages, and they do not have the responsibility for enforcement on projects other than their own.

Related to the problem of the regulation of construction and the application of technical knowledge in Turkey is the number and distribution of civil engineers in the country. Today there are approximately 6,500 civil engineers in Turkey to serve a population of approximately 35,000,000, or about one civil engineer for each 5,400 persons. (In the United States there is one civil engineer for approximately each 1,100 persons.) A complicating factor, moreover, is the great difference between living conditions in rural regions and larger urban centers which concentrates engineers in a relatively few cities. The two-thirds of the population that lives in villages and smaller urban centers has almost no technical talent available. The older six government-supported colleges of engineering, and the private colleges, all recently put under government control, are producing about 335 Civil Engineering graduates each year, and four new public colleges will soon increase this number. However, unless there is a redistribution of engineers, the likelihood is small for any rapid increase in construction advice for the majority of Turkish people.

A suggestion for increasing the number of Civil Engineers in rural areas is made in the Recommendations.

VII.

EARTHQUAKE DAMAGE - BURDUR AND BINGÖL

Ground Motion

No instruments recorded the ground motions in these earthquakes, and interviews with residents resulted in descriptions of ground motion that were so dissimilar, varying in duration from 5 seconds to 35 seconds in Burdur, for example, that they were judged to be of no value for engineering purposes. Much information is lost when ground motions are not recorded close to or on the foundations of damaged buildings, but until a recorder of very low cost is developed which requires no maintenance, most earthquake damage will have to be analyzed without having excitation records against which to evaluate building performance. Lack of knowledge about the excitation seriously impedes progress in improving the earthquake resistance of structures. Where one building falls and another stands, it is not sufficient to say this one was of poor design and the other good. It may be that the fallen structure was stronger than the one that survived, but it was simply subjected to more intense excitation, or this particular earthquake's frequency spectrum happened to closely match the natural frequencies of the fallen structure. Therefore, inspection of damage can reveal the modes of failure within one building, but comparisons between buildings should be viewed with caution.

Two impressions remain especially vivid in the observer's mind after viewing the destruction in Burdur and Bingöl: (1) Certain districts of a city or village suffered noticeably less damage than other districts, and (2) in some places certain specific buildings were heavily damaged, yet other comparable buildings nearby suffered only minor damage. Observation (1) could possibly result from varying intensity of ground motion caused by (a) focussing of seismic radiation by irregular boundaries of underground formations, (b) focussing of energy by ground velocity variations, whereby the wave energy converges at some point, (c) focussing of energy by multiple reflections, or significant excitation of natural modes of vibration of surface formations, or (d) the temporal and spatial patterns of energy release at the source being such that certain locations received greater or lesser intensity. (See for example References 5 and 6.)

That focussing of wave energy by geologic formations would single out individual buildings for destruction, leaving nearby buildings unscathed seems doubtful, but it is not yet proved or disproved. To study this phenomenon, ground motion measurements at 100 ft intervals would be needed. In the author's opinion the destruction of a single building in the midst of others much less damaged was due to one or more of the following factors: the dynamic characteristics of the building and its immediate foundation material were such that it was especially strongly excited compared to its neighbors; the building possessed a unique fatal structural weakness; and/or the ground motion at the building site was intensified by reflections of waves from foundations of adjacent buildings.

Surface Features and Ground Breakage

A map showing grossly exaggerated surface features of Turkey appears in Figure 8. Bingöl and Burdur are indicated by white circles. Mountain chains are seen trending parallel to the lines of epicenters which were shown in Figure 2. Figure 9 gives a closer look at topography near Burdur, including lakes, most of which do not have outlets. Burdur Lake is said to be connected underground with Aci ("bitter") Lake, to the northwest. Residents reported Burdur Lake has risen six meters or more since 1968 and destroyed farm land.

About 14 km southwest of Burdur on the lake shore plain, a small earth crack appeared, bearing N40°E parallel to the lake shore, for about one km along the line of a fault reported opened in an earthquake of October 3, 1914. Suggested evidence of the old fault was the downthrow of the land on the lake side by a foot or so in places. Figure 10 shows a close view of the fresh crack. Maximum downthrow of the lake side was about 14 cm, consistent with the movement of 1914, and suggesting a graben block movement. No lateral strike was observed. No crack was reported on the opposite side of the lake, and no sloshing of the lake was observed by the residents during the earthquake. About eight kilometers farther southwest, between Yaziköy and Hacilar, smaller tension cracking and sand boils were observed. At Yaziköy, a stream of sulphurous water as thick as a man, surging two meters high, was reported to appear during the earthquake and play for more than an hour afterwards.

In the topography near Bingöl, Figure 11, the drainage features running from Hazar Lake, through Bingöl to Karliova, roughly mark the left lateral strike fault which possibly connects the eastern end of the North Anatolian fault with the Dead Sea fault system (Reference 4). The drainage feature shaped like a shallow reclining "S", (Elmali River) just north of Karliova, roughly marks the North Anatolian fault.

The only ground breakage observed by the author in the Bingöl area was in the plain of the Göynük River, approximately eight kilometers due east of Bingöl, starting about one and one-half kilometers downstream from the damaged concrete bridge at the village of Köprübaşi, and continuing generally downstream on the east side of the river for about eight kilometers. Geologists from MTA (Turkish government mineral exploration group) reported that the cracking extended also north of Köprübaşi, but this was not seen by the author.

In general the broken ground was within a zone from six to twenty feet wide, trending N10° to 20°E, with sometimes one side downthrown by a few centimeters, sometimes the other. Cracks at 20° or so to the direction of the trace consistently indicated left lateral strike, although no markers could be found from which to definitely measure slippage, estimates of which varied from zero to 30 cm at different places. Near the village of Çeltiksuyu the crack crossed some low hills, where it sometimes temporarily disappeared, then reappeared shifted laterally by several meters. At one place the two main cracks bounding the cracked zone came together, and appeared to cross each other, forming an X-shaped crack. Figure 12 shows a part of the ground breakage.

In neither Burdur nor Bingöl was breaking of rock observed, nor was any damage seen due to shifting ground or landslides, or local soil failure.

Distribution of Damage

Figures 13 and 14 show isoseismal maps (MM) prepared by the Ministry of Reconstruction and Resettlement for the Burdur and Bingöl areas, respectively. Arabic numerals on these maps indicate the percentage of buildings destroyed or heavily damaged in each village as reported by the Ministry. Because of the differences in the quality of construction in different villages, percentages of buildings heavily damaged cannot alone be used to indicate relative intensity.

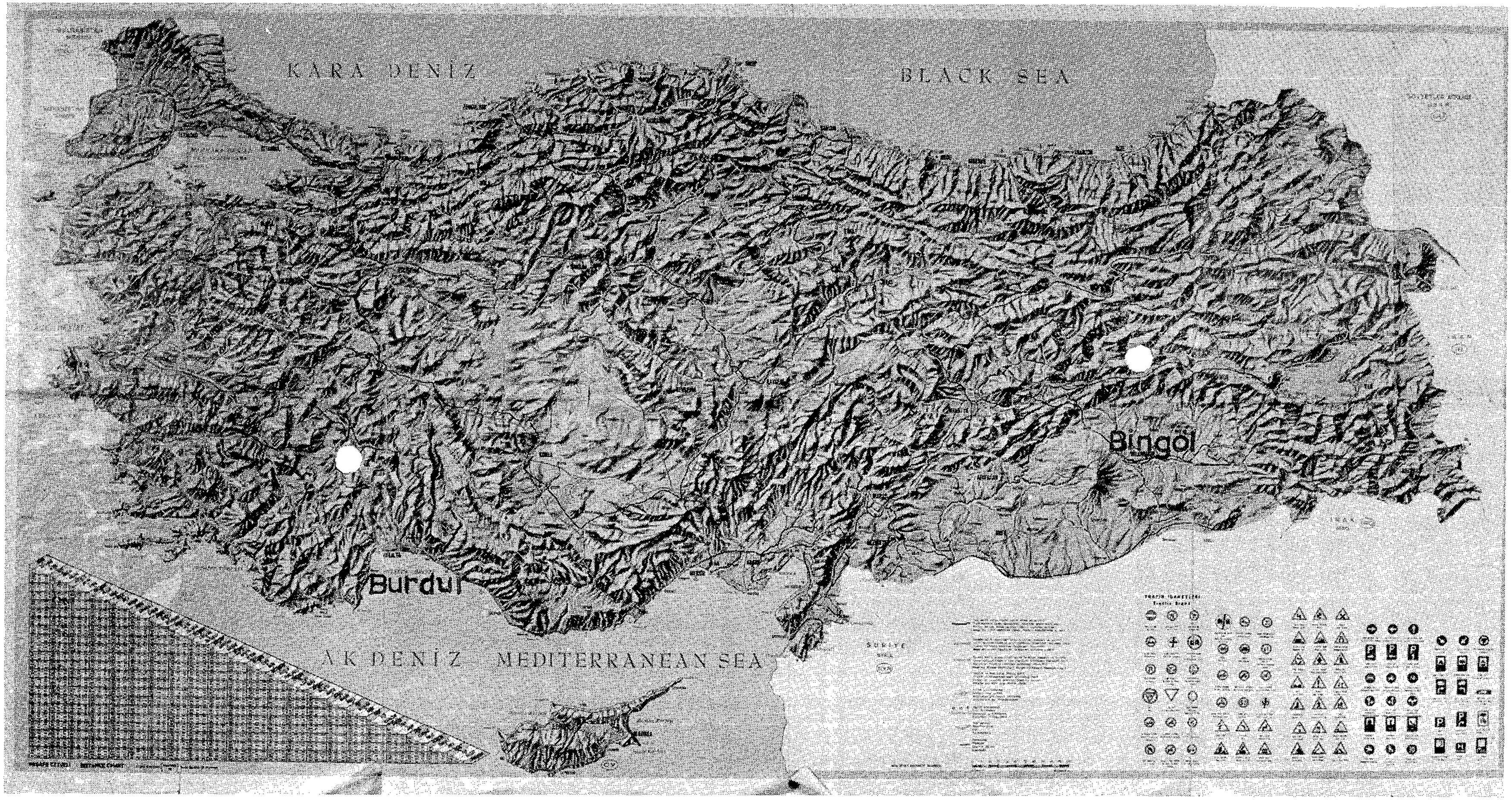

FIGURE 8 A map showing grossly exaggerated surface features of Turkey.

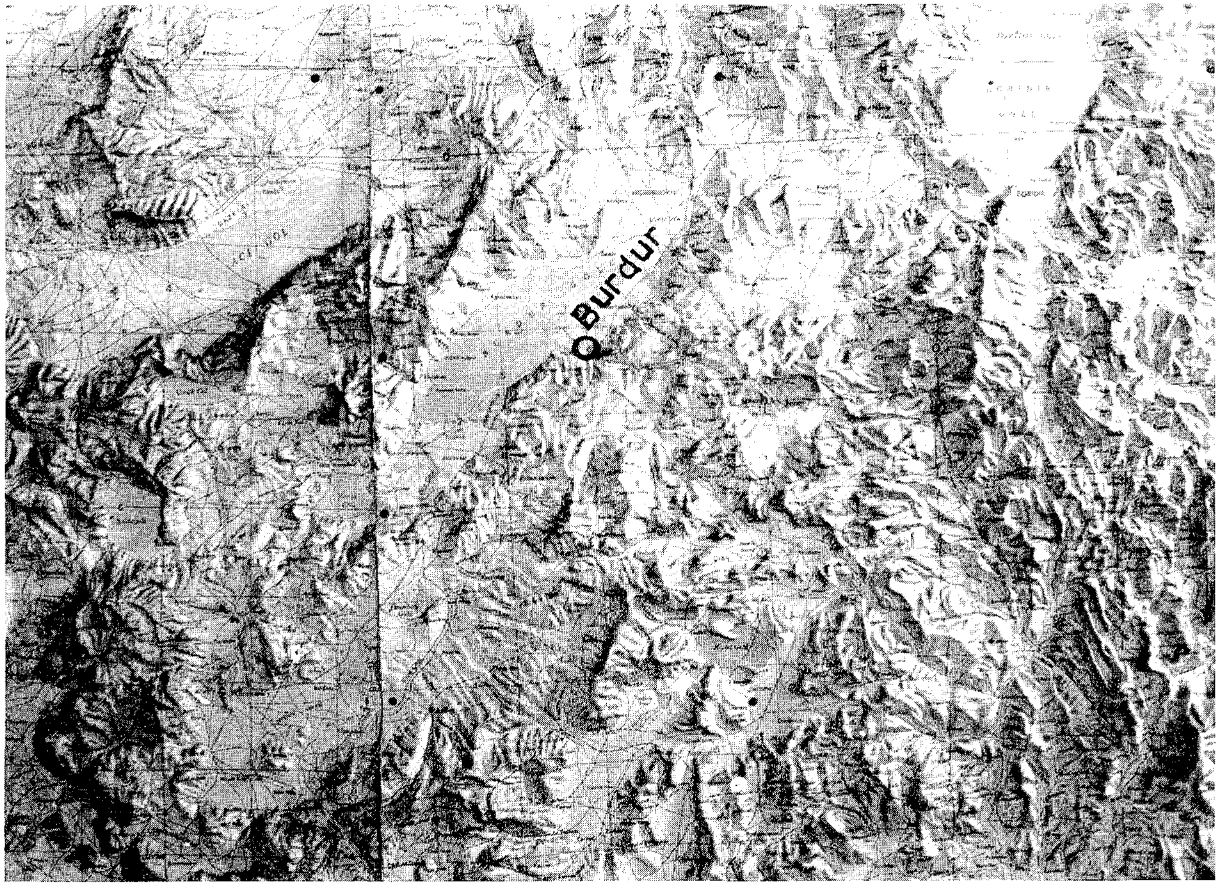

FIGURE 9   Topography in the vicinity of Burdur. It is suspected that the absence of outlets for Burdur Lake, Aci Lake, and other lakes in this section of Turkey is the result of uplifting going on in the area. Ground breakage in the latest earthquake, southwest of Burdur, along the lake shore, indicated the earth under the lake dropped a few centimeters relative to the dry land southeast of the lake.

FIGURE 10 Close view of ground breakage on the Burdur Lake plain about 14 km southwest of Burdur. Some earth has been removed from one side. The lake side of the crack is downthrown, supporting the idea that the lake results from graben action.

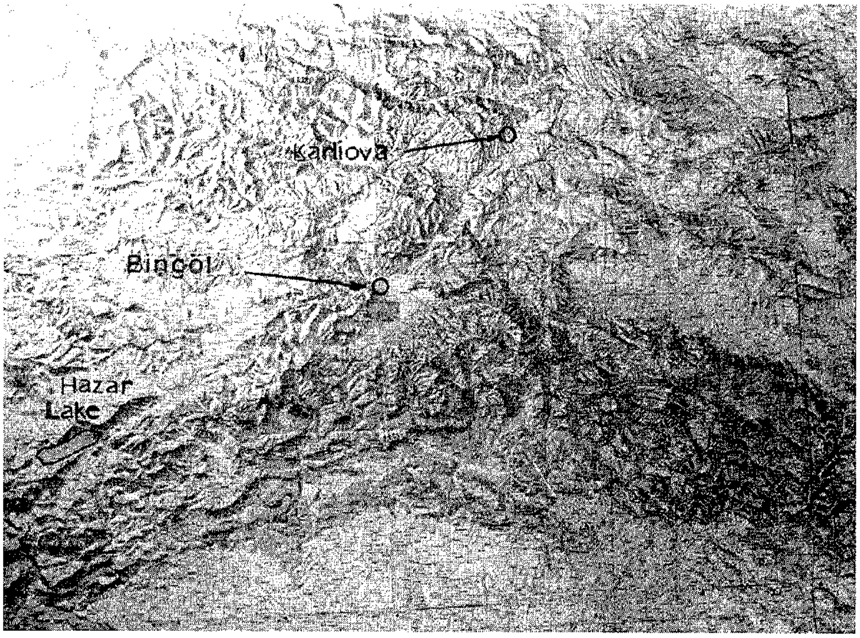

FIGURE 11 Topography of the Bingöl area. The fault shown by Allen (Figure 5) extending northeast of the Dead Sea fault system is thought to pass through Hazar Lake, in the lower left of this figure, and connect with the North Anatolian fault near Karliova. The shallow reclining "S" extending west and slightly north from Karliova (the valley of the Elmali River) roughly marks the North Anatolian fault.

FIGURE 12 Ground breakage near Çeltiksuyu village, where the crack left the Göynük River bottom and traversed some low hills.

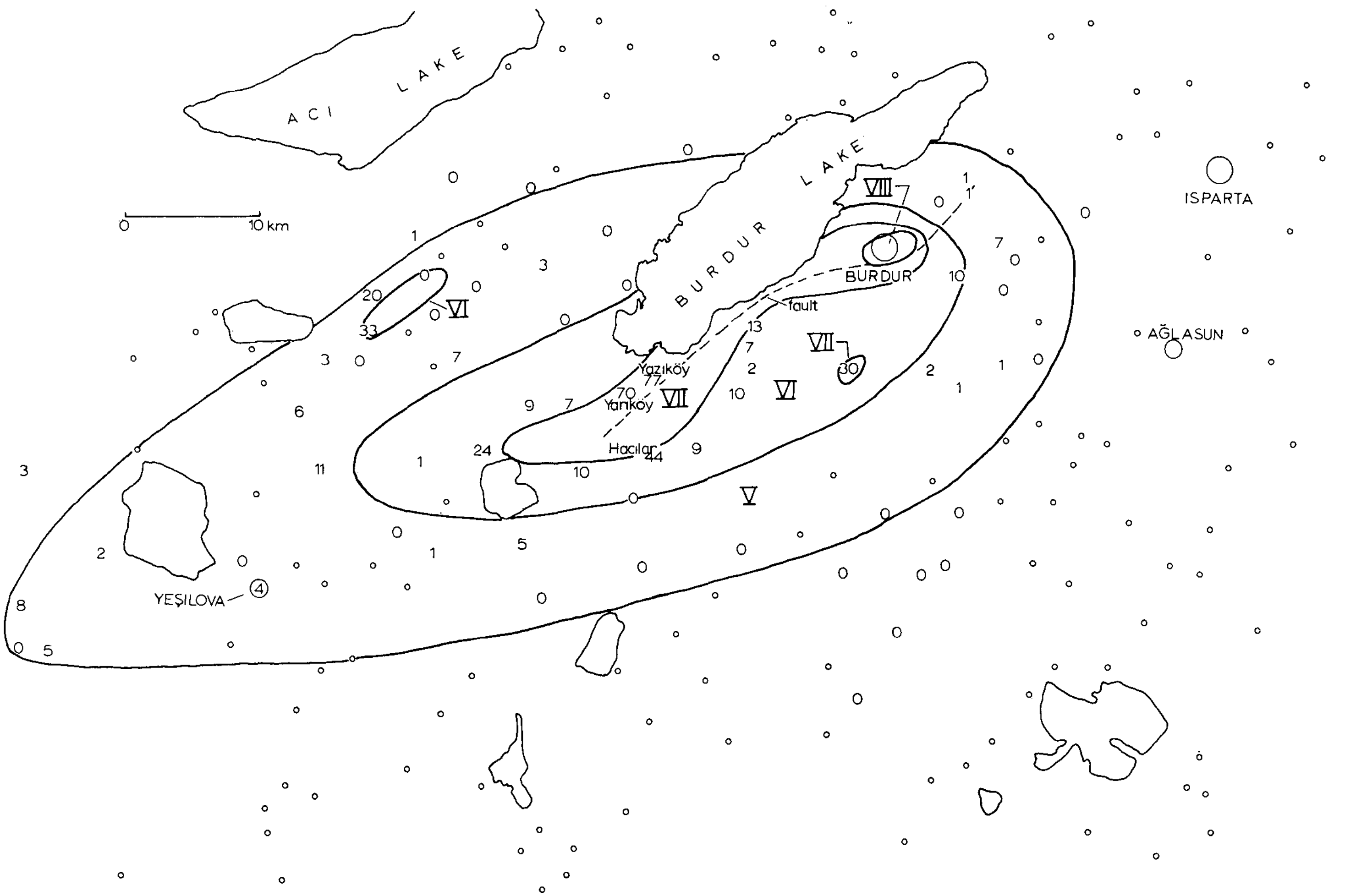

FIGURE 13 Isoseismal map of the Burdur region prepared by the Turkish Ministry of Reconstruction and Resettlement (Reference 10). Superimposed on the map are numbers representing the percentage of structures heavily damaged in each settlement. No data have been reported from the settlements represented by very small circles.

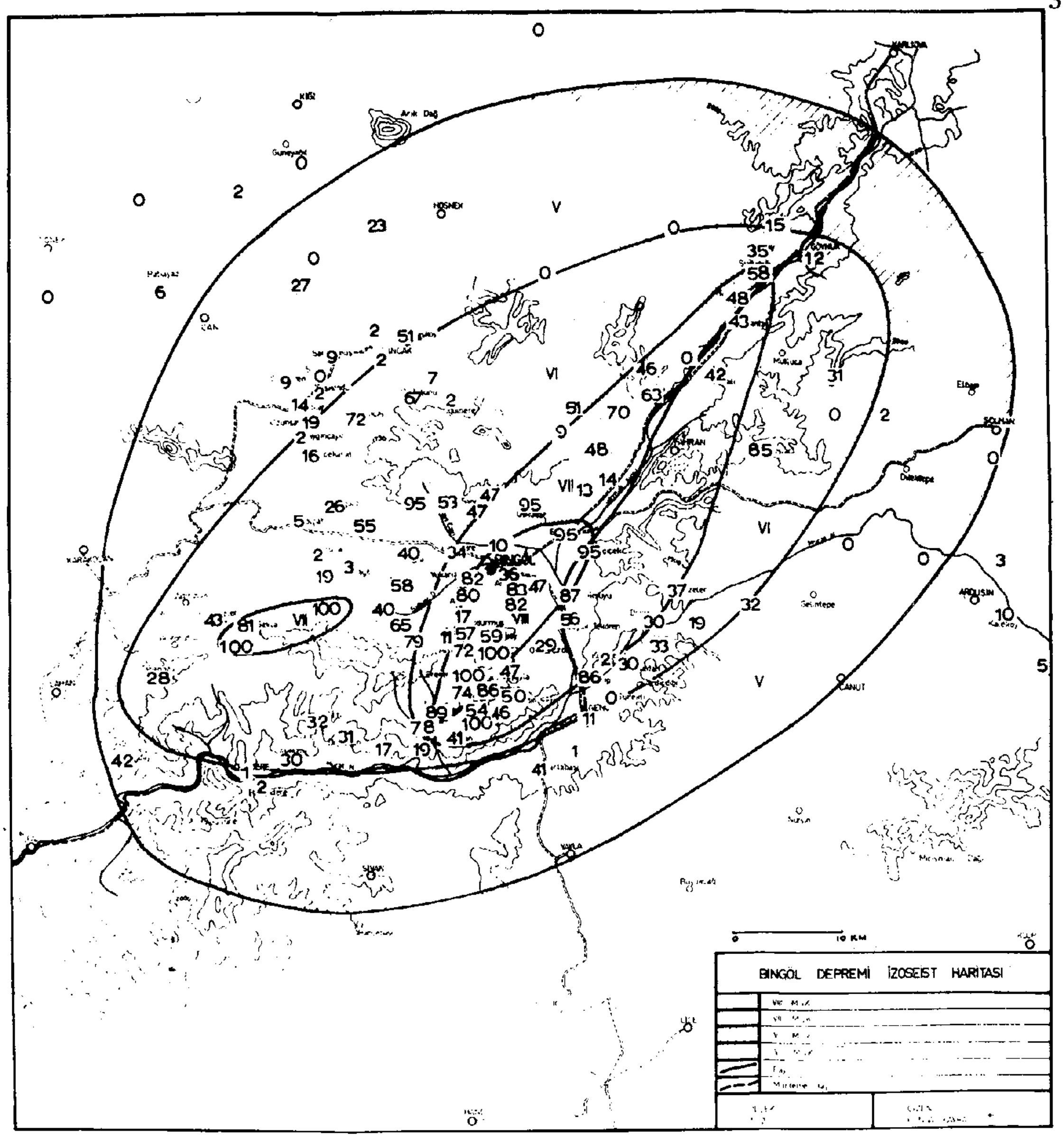

FIGURE 14 Isoseismal map of the Bingöl region prepared by the Turkish Ministry of Reconstruction and Resettlement (Reference 11). Superimposed on the map are numbers representing the percentage of structures heavily damaged in each settlement. Not shown are an estimated 150 additional settlements. The heavy line running NE through the center of the map is a recognized fault. The dashed portions represent assumed extensions.

Damage to Houses of Adobe and Uncemented Stone

Here and there in areas of heavy damage, adobe houses and houses of uncemented stone surprisingly withstood the earthquakes relatively unscathed. Such occurrences are viewed by the author as generally due to local pockets of less intense ground motion, at least in certain frequency ranges. Of course, no measurements of motion are available to verify this hypothesis. In addition, cracks and relative movements within the walls in loosely jointed structures are not always easily observable. Relative movements probably took place within the walls of apparently undamaged buildings, but just what such movements mean in the way of damage is not clear. Controlled shaking experiments with structures of this type must be conducted for a better understanding of their behavior.

In Bingöl, it appeared that the stones in the walls of many of the houses of uncemented stone were displaced at the top first, and then the failure proceeded downward. In some cases walls pulled apart at the corners and tipped outward about the base. And in some houses, particularly those of two stories, cracks appeared near corners, between the floors, and the walls then expanded and came apart. Often, when walls were made of smaller stones, outer layers of stone fell out, decreasing wall thickness.

No consistent method of failure was observed in adobe houses, but in general, having some cohesion, the walls broke up into large chunks, rather than simply shattering into the individual building pieces, as was seen in the stone houses in Bingöl.

Most of the wall material in these buildings fell outward, and deaths resulted more from roofs and upper stories falling on occupants, rather than walls. Braced wood frames, capable of carrying roof loads, built inside and separate from the walls, would mitigate this hazard until economic conditions advance to the point where adobe and uncemented stone are no longer used. This is discussed more fully in the section on Recommendations. The captions with the figures that follow of damage to houses of adobe and uncemented stone make the figures self-explanatory.

Damage to Masonry Buildings

Without knowing the ground motion at each building, one cannot ascertain whether masonry buildings performed satisfactorily in the earthquakes of Burdur and Bingöl. However, certain weaknesses of the buildings were apparent.

In buildings in Bingöl, mortar was hard, but bricks were weak; in Burdur bricks were stronger, but most mortar was easily powdered in the fingers, and the travertine stone used in the lower stories was very weak in shear. Only a few masonry buildings in Burdur collapsed completely, but well over half suffered major cracking that required repairs other than plastering over the cracks. There were numerous collapses in Bingöl.

If stronger building materials had been used, would damage have been significantly less? A few buildings in Burdur had foundations of a hard stone-limestone or a fine grained sandstone. None of these structures, even though mortar was not of top quality, showed severe damage. On the other hand, most of these were observed to be one story or more shorter than their heavily damaged neighbors with travertine foundations, so a clear comparison is not possible. It seems certain, however, that better mortar, stone and workmanship would have significantly reduced damage in Burdur, but stronger bricks in Bingöl would probably not have made much difference.

Would damage have been lessened by adherence to more conservative design principles, such as reduction in the number and size of wall openings, elimination of offsets in walls, making the buildings more symmetrical and/or making walls thicker? Probably these changes would have reduced damage, and yet the tastes of most people demand other than plain symmetrical buildings with only a few small windows. Restricting masonry buildings to one story would certainly reduce damage, but the economics of city life demand multi-story buildings, with most stories above ground level.

Masonry buildings of three or four stories will probably house a significant portion of Turkey's citizens for many years to come, and will represent a sizeable investment of the nation's wealth. As such, their earthquake resistance should receive serious consideration. A few suggestions for masonry buildings are given in the Recommendations.

The captions with the following figures of masonry buildings make the figures self-explanatory.

Damage to Reinforced Concrete Structures

In a developing country accustomed to building with adobe, masonry and wood, the term "reinforced concrete" signifies a technology which creates buildings stronger than is possible with the traditional methods. Unless the design and workmanship are properly done, however, reinforced concrete buildings can be weaker than masonry buildings and can turn out to be an expensive disappointment to the people. In Burdur, several reinformced concrete buildings built by government agencies were seriously damaged, whereas a short distance away, some masonry buildings, less tall, showed only minor damage. Ground motions at the two sites are not known, so a meaningful comparison between the degrees of damage cannot be made; only obvious shortcomings of the damaged buildings can be pointed out.

It was commonly observed in damaged buildings that the quality of concrete and the placement of it were poor. Concrete from which the stones can be dug out with a pocketknife is not strong enough for most structural uses. Poor placement was usually exemplified by dry mixes insufficiently worked, and containing large voids which were later hidden by plaster. In columns, especially, weak joints were obvious where one load of concrete was dumped onto another, without vibrating or working to mix the two into a homogeneous mass.

Obvious design errors included making columns weaker against horizontal forces in the longitudinal direction of a building (probably on the false assumption that when there are many bays, one need not design for horizontal forces in that direction), providing insufficient column ties near column-beam joints, and anchoring reinforcing bars within joints. Less obvious may have been the failure to consider different relative stiffnesses of columns against lateral movement where some columns are buried in heavy masonry walls, and others are free to deflect over their full height. In addition, the adequacy of the lateral force requirements in the Turkish code to protect buildings against forces of the magnitude generated during this earthquake can be questioned. Perhaps the Turkish code should demand more lateral resistance.

The following figures of damage observed in three new reinforced concrete structures are captioned to make them self-explanatory; they are considered to be typical of damage to reinforced concrete buildings.

Damage to Bridges

There are several short concrete bridges in the Burdur area, but no damage or movement relative to the abutments was noted. In the Bingöl area there are two multi-span bridges, one of three steel spans, 165 m total length, across the Murat River, 17 km SE of Bingöl, and one of five concrete spans, 120 m total length, across the Göynük River, 10 km east of Bingöl. Although shorter bridges in the Bingöl area were not affected by the earthquake, both of these longer bridges were damaged. The steel bridge was damaged chiefly by the rotation of one pier, whereas on the concrete bridge the damage resulted from several causes. The captions with the figures which follow make them self-explanatory.

Observations on Housing Construction and Materials

From even a casual study of the damages to housing caused by these earthquakes, it is apparent that the traditional materials and methods of construction are extremely vulnerable. Achievement of any significant improvement of seismic safety in the villages of Turkey will require the use of more efficient structural materials and/or methods of construction. Some observations concerning these topics are presented in the captions of the figures which follow.

VIII.

RECOMMENDATIONS

After viewing the earthquake damage at Burdur and at Bingöl, and after talking with officials of the national and local governments, the author of this report concluded that the recent disasters resulted directly from inadequately constructed buildings. This was due partly to poverty, high building material prices relative to incomes, lack of knowledge of good construction practices among most of the people, lack of enforcement of existing building regulations, and inadequacy of the building regulations. It is believed that the risk of damage and the number of casualties from future earthquakes could be significantly reduced if the following measures are taken:

1. Enforcement of the building codes should be administered by an agency of the national government charged specifically with this duty. If the agency finds that the codes are not being enforced in certain areas, it should have the authority to assign engineers to these areas to establish offices and assume the duties of approving the structural portions of plans, inspecting construction, and granting or denying occupancy permits for completed structures. In addition to enforcing the building codes, this would help in achieving a more uniform distribution of construction engineers around the country.

2. Buildings with mud roofs should not be used as human habitations.* Such a restriction could work a severe hardship on very poor people, and some relief for them would have to be provided - perhaps government-supplied corrugated galvanized steel sheeting or corrugated cement-asbestos sheets with fine wire (poultry) netting attached to the underside so that a layer of leaves or other insulating material could be stuffed between the netting and the roof to provide insulation. Plaster on the underside of the wire netting would seal the insulation from rodents and reduce fire danger. A sketch of such an arrangement is shown in Figure 94.

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*The present code does not permit flat mud roofs in No. 1 Earthquake Zones.

3. Persons living in houses with walls of adobe or of stones set in mud mortar or no mortar at all should be educated about the safety provided by braced timber frames built on the inner side of such weak walls. Well-braced frames should be capable of carrying second floor and roof loads without reliance on the adobe or stone walls. Exterior walls of mud or stone would be used only for insulation, privacy, and protection against the weather. If the frames were built on the inside face of the walls rather than being incorporated into the walls, there would be less likelihood of the frames being torn apart when the walls break up during an earthquake, and the danger of the walls collapsing inward on the inhabitants would be reduced. The use of adobe for interior walls should be discouraged, a possible substitute being wood-framed walls with wood lath and mud or lime plaster.

4. It does not appear at present that many villagers would be able to pay for lumber shipped to them from the forested regions to build house frames. However, fast growing poplar trees can be grown over much of Turkey, as demonstrated in many villages by the plantings for shade, fuel, and lumber. With government encouragement, it would be feasible to greatly increase local poplar plantings and designate.the plantings for building purposes or as replacements for present trees that could be harvested for lumber in the very near future.

   A single story house 24 ft x 32 ft, with a lightweight roof, would require about 900 board feet of lumber for just the wood columns (4 in. x 4 in. at 8 ft spacing) and bracing (x-bracing of 4 in. x 4 in. for each panel) in the exterior walls, plus one interior braced wall. One 20 in. diameter poplar, 24 ft long, would provide perhaps 225 board feet, so four trees of this size would provide lumber enough for the earthquake protection. Lumber to support the roof, including rafter ties across the top of the walls, might require an additional 600 board feet, more or less, depending on snow load, so seven logs would provide enough structural lumber for one complete house. In a village of 1,000 persons, assuming five persons per house, the lumber could be obtained from perhaps 1,400 trees. This is more than seems to be presently available in most villages, so plantings should begin now if local timber is to be used. This quantity of trees could easily be grown on less than four acres.

Although the use of local timber plantings for structural lumber may not agree with plans for the development of Turkey's national economy, still, from the standpoint of saving lives in earthquakes, such use deserves serious consideration, until the cost of steel and masonry building materials is within the reach of the rural population.

5. To be used effectively, timber must be sawed into pieces of proper size to carry the loads, and to facilitate joining, but most Turkish villages have no sawmills, and a great many have no electric power. Where local timber is available, this need could be met by a schedule of periodic visits by portable gasoline or diesel-powered sawmills. Undoubtedly, government assistance would be necessary to get many such sawmills into operation and perhaps keep them operating.

6. There is a great need for more practical research using large shaking tables to test ways of constructing masonry buildings with increased earthquake resistance. It was previously suggested that braced timber frames built on the inner side of the adobe walls of village houses would make them safer. Other questions that might be considered:

    a. Can wood or concrete diagonal members be incorporated into brick walls to provide lateral resistance without unduly lowering the capacity of the walls to carry vertical loads? Can such members be used outside the brick walls?

    b. Can bricks be laid in patterns other than the conventional stretchers and headers to increase lateral resistance of walls without excessive weakening in the vertical direction?

    c. Can an inexpensive method for making hollow bricks by hand labor be developed? Such bricks could be used as fill between the structural members of braced wood walls in place of the solid bricks presently used. They would serve as insulation, as a surface on which to apply plaster, and could be used alone for interior partitions.

   d. Would rounding the corners on brick buildings increase their earthquake resistance?

   e. If an adobe house were built as a cylinder (round in plan), would it be more earthquake resistant?

   f. If buildings are built in a long row, all the same height and with sides touching, are they more earthquake resistant than those standing separately? Mr. Elhami detected some evidence of better performance of this type of construction in Burdur. This question could not be fully answered by a shaking table investigation because the table provides uniform base motion, whereas, in practice, variation in ground motion may occur over the length of the row.

   g. Should stairways be isolated structurally from a building or should they be designed to transmit lateral forces between the floors?

   h. Does presoaking bricks and tapping them with a trowel when they are set in mortar significantly increase the strength of a brick wall?

   i. If bricks were produced with fine steel wires protruding from them, would tensile and shear strengths of mortar joints be increased?

   j. Can an adobe house or any part of it be fired in place, fusing the clay bricks together within the walls, thus increasing strength?

   k. If bricks had knobby surfaces in contact with the mortar, would the shear strength of walls be increased?

7. Further structural use of travertine, which is now common in Burdur's buildings, should not be permitted. Existing structural applications of it should be replaced by stronger construction.

8. A caravan which would travel to village centers, demonstrating the superior resistance to ground motion of properly built houses, would

be effective in educating villagers about earthquake resistant construction.

It is suggested that a travelling demonstration be put together, consisting of two large dump trucks, plus a flatbed trailer on which two houses 10 ft x 12 ft or so could be built. For the demonstration, the trucks would be loaded with earth or rocks to provide mass, and on the trailer two houses would be built by the villagers, one in the usual fashion with adobe or stones set in mud mortar, and perhaps with a mud roof, and the other similar, but with a braced wood frame inside the walls, and a light roof.

The trucks, at opposite ends of the trailer, would then batter the trailer back and forth until the houses were destroyed. Stiff springs between the trucks and the trailer, and proper separation of the motionless truck from the trailer, would provide some control of the sharpness of the shocks and the time interval between a pair of shocks. This type of demonstration, using only simple equipment, should be instructive not only to villagers but to engineers as well.

9. Changes are necessary in the regulations now in use for construction in Turkey's seismic zones. Although present workmanship in construction is often of lower quality than is assumed when designs are made, it is not recommended that the code make allowance for this, but rather that inspection and enforcement be increased to raise the level of performance of workmen to that assumed in the design. The present code is being revised, and some obvious errors, inconsistencies and omissions will undoubtedly be corrected. The author recommends especially that lateral force coefficients be increased significantly, particularly for stiff brittle structures, and that braced frames be required in all new construction of adobe or uncemented stone.

IX.

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FIGURE 15 A lesson concerning adobe house construction is illustrated in this figure. The roof is at least partially supported by wood columns, and although the front wall collapsed, the roof did not.

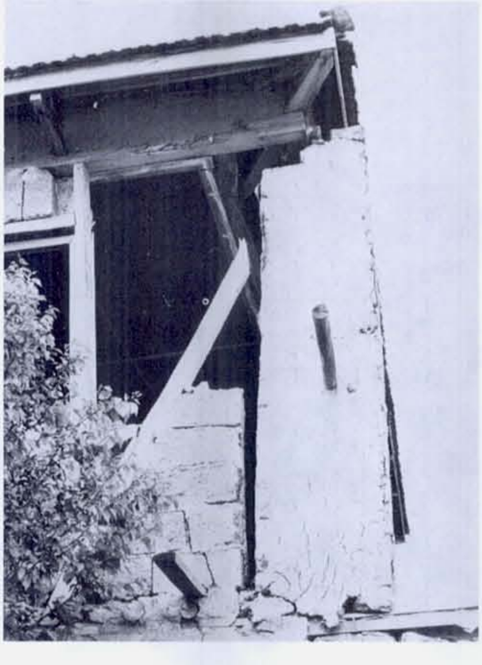


FIGURE 16 A common mode of failure of adobe houses in the Burdur region was the separation of exterior wall corner joints, permitting walls to tip outward. Often a wall was braced perpendicular to its plane by embedding a piece of wood at eye level in the adobe, then installing a diagonal brace from this to the floor. Usually only one or two nails were used, loaded in tension when the joint tried to open. It was always observed that the nails pulled out or broke through the diagonal; in no case was the embedded wood pulled loose.

FIGURE 17 Temporary wood braces have been installed to prevent further collapse of this adobe house in Yaziköy, Burdur. In the second story the side wall and the front wall appear to have had no connection. First story walls are probably tied to each other only with interlaced adobe bricks. Is there a relationship between failure of the lower corner and failure of the second story side wall?
(Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 18 This two-story adobe house, on the verge of collapse, contains lateral bracing in the first story. The 60-cm thick walls with wood posts around the windows appeared very strong to the builder, but proved quite inadequate under lateral loading. The front wall in the second story, probably braced like the house in Figure 17, remained rigid, but could not save the building.
(Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 19 This type of construction, in Askeriye, near Burdur, is common in villages on sloping ground. One- and two-story houses are intermingled, the roofs of the one-story houses serving as working platforms. One can easily imagine that when an owner needs more living space, he simply lays up more adobe walls on top of the first story. The tremendous weight and fragility of such structures is frightening.

FIGURE 20 A close-up view of the house in Figure 19, showing the heavy roof and the walls of uncemented stone and adobe.

FIGURE 21 Showing the construction of a mud roof on an adobe house. Successive layers of logs and poles, at progressively closer spacing, support finally twigs and leaves, with mud on top. More mud is added over the years to keep the roof watertight.

FIGURE 22 This house under construction in Yazikŏy, Burdur, has diagonal bracing in upper interior walls, but none in the front wall. Perhaps the hip roof, a rather rigid construction, held the second story walls together. First story adobe walls, without diagonal bracing, are heavily cracked. Mud plaster covers the adobe on the left side.

FIGURE 23 This two-story adobe house in Yazikŏy, 20 km SW of Burdur, survived, although 193 out of 250 houses in the village collapsed or were heavily damaged. Poplar trees, as seen here, are commonly planted in the villages for fuel and lumber. Increased plantings of poplars and proper instruction for their use in building braced frames in houses would reduce earthquake fatalities.

FIGURE 24 In the village of Kişla, near Burdur, a region of light shaking, the face of a stone wall laid in mud mortar has fallen due to lack of long stones to tie the faces together. This mode of failure is not uncommon in thick stone walls. Next door the lightly braced second story of poorly laid brick appears to have lost one triangular panel of brick. As flimsy as it is, the wood framing probably supports the roof, but the brick walls contribute the greatest amount to earthquake load.

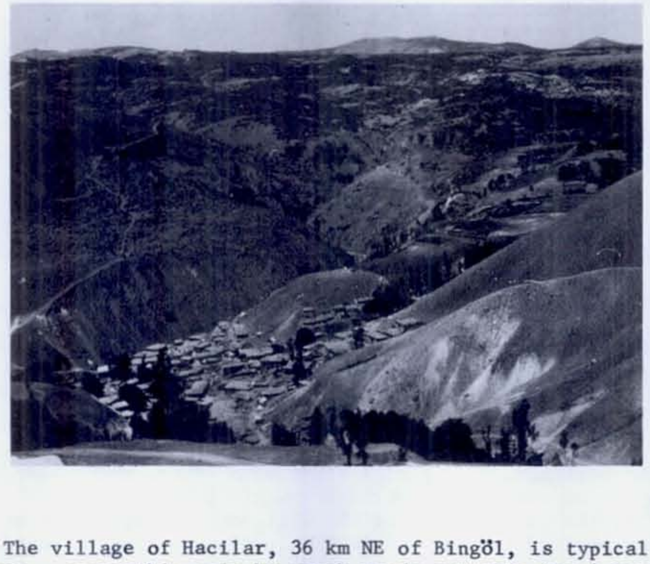


FIGURE 25 The village of Hacilar, 36 km NE of Bingöl, is typical of many Turkish villages - accessible only by rough roads suitable for 4-wheel drive vehicles, and without electricity. The economy is based on grazing, small farms and gardens, exported workers, and rugs woven by the women. Cash for such things as cement and sawed lumber is scarce, so construction makes use of local stone, mud, and poplar poles. Winters here are as severe as Montana's. Note the poplar trees growing in the draws.

FIGURE 26 Most of the houses in Hacilar are one-story, of uncemented stone, with wood bond members built into the walls. In the foreground the bond members failed to hold the corner together. In the background the building with squared stones appears to be laid in cement mortar, but the mortar is on the surface of the joints only, and no mortar was observed inside the joints. The earthquake displaced some stones perpendicular to the wall and opened cracks between others. The villagers said the squared stones came from "ancient constructions."

FIGURE 27 The beginning of disintegration of a stone, mud-mortar house in Ekinyolu. Note the corner cracks, perhaps inhibited by the wood bond members, and the falling out of the outside face of the wall near the roof. Under continued shaking the upper part of the wall would likely disintegrate, allowing the roof to fall in.

FIGURE 28 Another example of the early stages of failure of a stone, mud-mortar wall - falling out of the outer surface and collapse of the upper portion of the wall which is not tied by the roof beams. There is also some corner cracking.

FIGURE 29 This 30-year old primary school in Hacilar, 22 km SW of Burdur, partly brick, partly coarse masonry, was laid in mortar which easily could be powdered in the fingers. Perhaps the nonsymmetry of the second story was responsible for the damage there being greater than in the first story.

FIGURE 30 Another view of the Hacilar primary school.

FIGURE 31 The foundation of the 1½-story school in Hacilar, in the Bingöl district, was laid in hard cement mortar, but upper walls were of rubble laid in weak mortar. Above the windows were a reinforced concrete collar beam and a roof of corregated steel. No foundation damage was evident, but the rubble walls simply fell apart in places. The weakness of walls made of small stones which do not extend completely through the walls, laid in poor mortar, is obvious.

FIGURE 32 End view of a damaged wing of the government building in Bingöl. Cracking in second stories was unusual in Bingöl. Note the cracks seem to start (are widest) at the corners of the building, at the top, where dead load compression is least. Cracks of x-shape occurred in the first story, but cracks were only in one direction in the second story. Perhaps under continued shaking, x-cracking would have occurred in the upper story, resulting in the upper corner dropping out.

FIGURE 33 The foundation walls of most of Burdur's apartment buildings are made of a porous travertine, consisting of rather hard shelled tubules, randomly spaced, with softer material, almost like rotten bone, between the tubules. The Turkish name for the stone, mined a short distance SE of Burdur, is "Kurna." Here the author has easily thrust his pocketknife, not into a joint or a crack, but into the solid stone itself.

FIGURE 34 A close-up of a shattered travertine foundation wall in Burdur. The stones vary in quality, but usually they contain bands of fibrous of porous material, easily penetrated with a knife. Mortar is probably weakened by the absorption of moisture into the porous stone.

FIGURE 35 This building has been evacuated because the travertine foundation walls are shattered. The next figure shows the building adjacent to this one.

FIGURE 36 Next door to the building with shattered foundations in the previous figure stands this structure which had only minor cracks between foundation stones. The two buildings differ in that this is one story less, and its foundation is made of hard stone. Did the stone or the extra story make the difference in damage?

FIGURE 37 The situation pictured here is similar to that illustrated in the two previous figures. The buildings on the ends have travertine foundations, and are badly cracked (see the following figure), but the building in the center, one story shorter, has a foundation of hard stone - limestone or a very fine-grained sandstone - and it suffered no cracks at all. In this neighborhood of Burdur there was great variation in damage, even among buildings with travertine foundations.

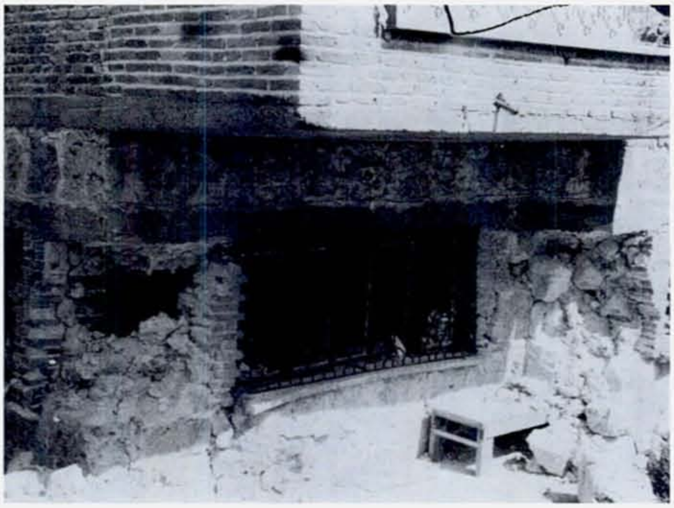


FIGURE 38 A close-up of the nearest building in the previous figure. The walls are very close to complete disintegration.
(Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 39 Seven persons were killed in the collapse of this 3½-story masonry apartment building in Burdur. Mortar was made from lime and sand, and travertine was used in the exterior wall, in the lower story. Possibly the walls of the lower story disintegrated unevenly, causing the building to tilt, thereby increasing the shear force on the walls of the upper stories to the point of failure. This building, on a corner lot, was the only collapsed structure for several city blocks. Others in the immediate vicinity suffered cracked lower story walls, but not to the point of disintegration. (Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 40 An older structure in Burdur, from which the plaster cracked. The bracing is not ideal, and the lack of continuity of the columns shows ignorance of structural principles, yet the construction is much better than plain adobe. The use of brick or adobe infill in braced wood frames as insulation and plaster base is common in older structures. This type of construction would have much merit if proper framing was used with hollow inexpensive bricks.

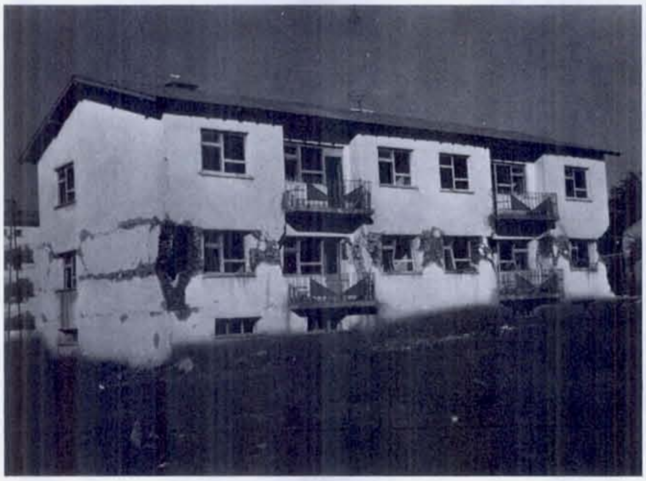


FIGURE 41 This figure and the six following figures show successive views, moving counterclockwise, of a badly shattered apartment house in Bingöl. This view shows principally the north face, as well as the east end wall. A floor plan of the building, made from measurements, is shown later. Note that damage is confined almost exclusively to the first story - perhaps due to the brittle nature of the masonry. Cracking of the first story possibly resulted in reduced lateral force in the second story.

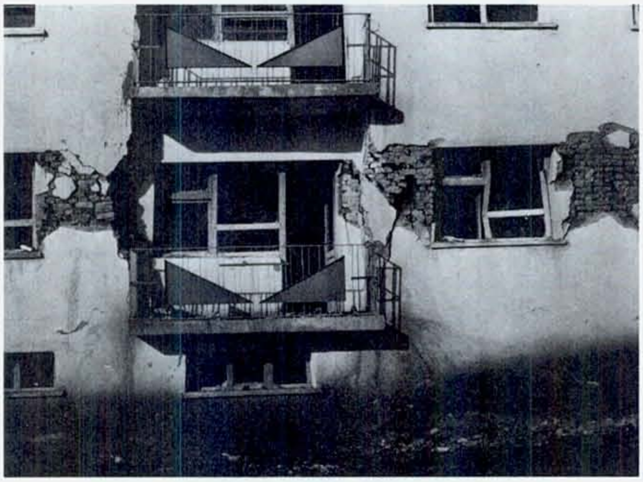


FIGURE 42 A closer view of the east balcony on the same (north) side of the building shown in the previous figure.

FIGURE 43 A close-up of the pier west of the west balcony, north side. Bricks in the Bingöl region were soft, but mortar was of good quality.

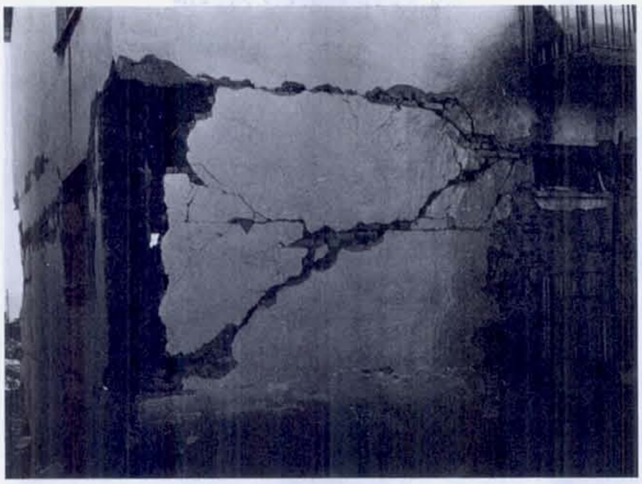


FIGURE 44 A view of the southwest corner, south wall in the foreground. Once the corner has fallen, a single diagonal crack meeting a horizontal crack on the bottom of the collar beam is enough for a large segment of wall to be lost. The collapse of the corner, the large diagonal crack, and the distortion of the frames of the small windows indicate that the second story shifted left relative to the first.

FIGURE 45 Both stories of the south face, southwest corner.

FIGURE 46 The south face, at the southeast corner.

FIGURE 47 The east face.

FIGURE 48 Interior walls of the building shown in the preceding figures were just as badly shattered as exterior walls.

FIGURE 49 Gate posts at the park entrance in Burdur were shattered, whereas across the street, some 200 feet distant, rather tall chimneys in the government building (Figure 51) did not fall.

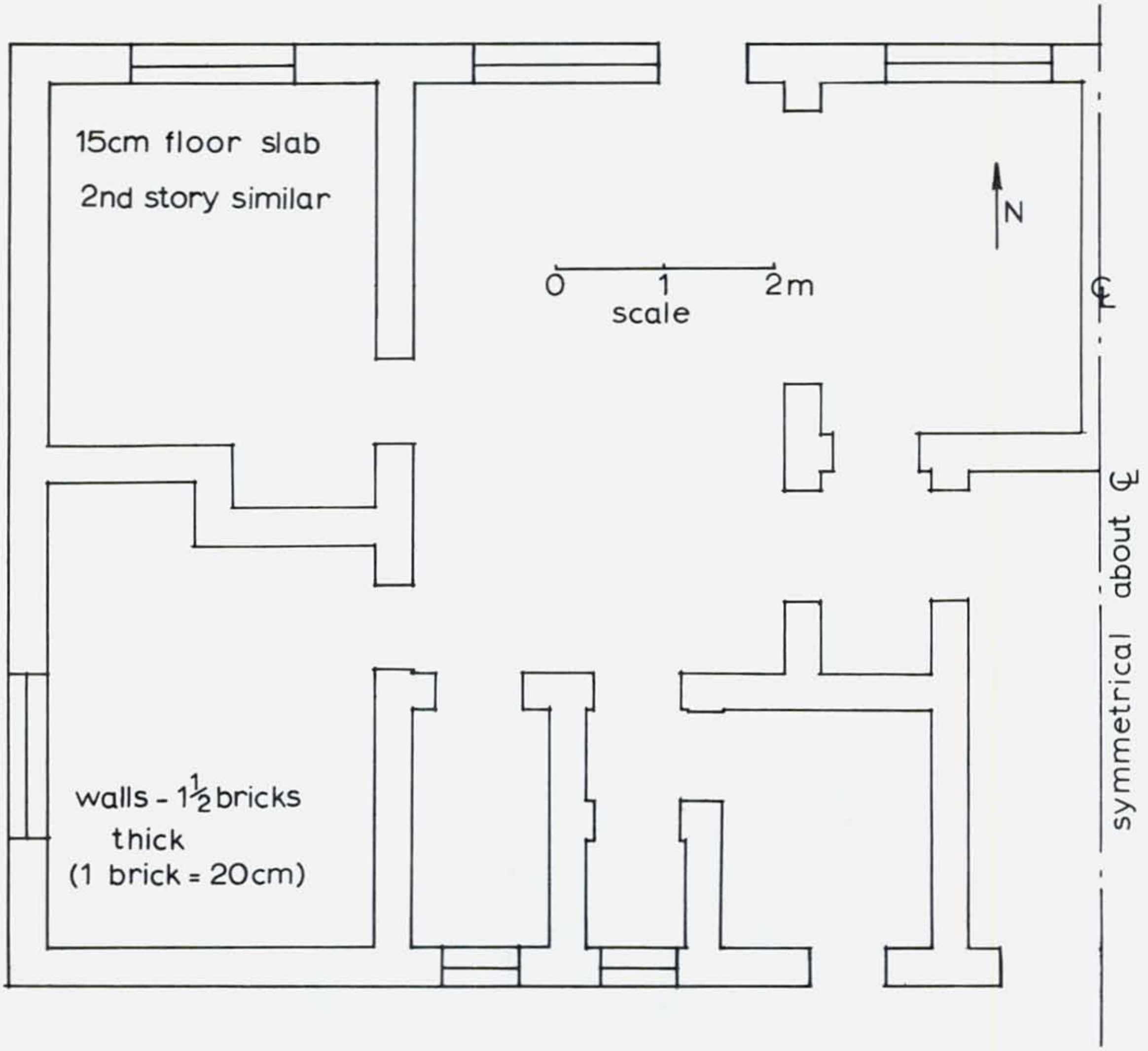


FIGURE 50 A floor plan of the shattered two-story apartment building shown in the previous figures. Note that openings occupy about 55% of the length of the north wall, greater than the 40% maximum prescribed in the Turkish code, and in the east-west direction, the lateral resistance provided by interior walls is scant.

FIGURE 51 The government building in Burdur, made of hard stone set in lime mortar, had some plaster cracking inside and perhaps some mortar joint cracking, but not extensive. The building continued in use after the earthquake. The chimneys on this building, some of which had guy wires, and those on the building next door did not fall or appear to be damaged. Tents in the garden were used by officials for handling relief work.

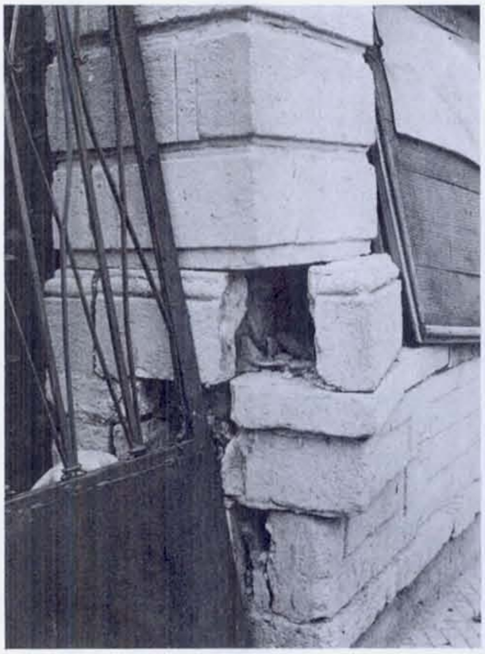


FIGURE 52 A close-up of the gatepost damage at the park entrance in Burdur. Although the exterior was made of well-fitted stones, the interior was filled with rubble laid in weak mortar, a common practice in ancient times as well, as evidenced in the many Roman ruins in Turkey.

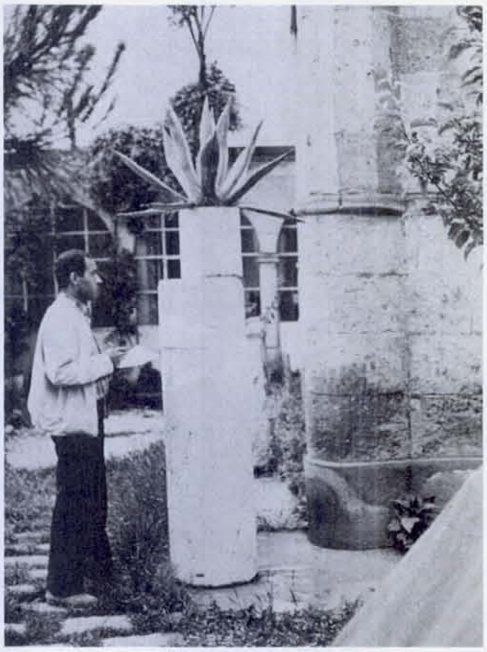


FIGURE 53 This section of an ancient stone column on display in Burdur's museum, 40 cm diameter by 154 cm tall, can be easily rocked by hand, yet it did not topple during the earthquake. The flower pot on top was displaced about 10 cm, but did not fall off.

FIGURE 54 A top-heavy stone carving, about 2 m tall, probably originally a fountain, could be easily rocked by hand, but was not toppled by the earthquake. In the background is seen the bus station building, under construction, which suffered fallen brick walls in the penthouse.

FIGURE 55 This crude shed in Bingöl illustrates a principle. The brick walls collapsed, but the roof, supported on wood columns, even though they were unbraced, did not fall. On the right, not completely shown, a roof supported on only brick walls came down with the walls. Braced frames which could carry roof loads, even though masonry walls fall, would offer considerable added safety in masonry structures.

FIGURE 56 Most of the unreinforced masonry minarets in Burdur suffered displaced stones near the top. Lower portions did not show damage. On the other hand, in Yaziköy, 20 km SW, this minaret was broken off at the base. The sheet metal cap covering a wood frame on top of the Tabac Mosque has been torn open by workmen in preparation for dismantling the top portion. Possibly the discontinuance above the balcony of the interior stone steps, built between a central stone column and the outside wall, was responsible for the damage being localized in the top section. The reinforced concrete building with broken windows in the background (shown later) had heavy partition damage as well as structural damage.

FIGURE 57 Yeni Mosque, just east of the fairgrounds in Burdur, suffered badly cracked cinder block walls between concrete columns, but no damage to major columns. So little cement had been used in the cinder blocks that they could almost be broken in the hand. The undamaged minaret, not yet completed with a cap, should be a model for future minaret construction. Reinforcing steel, just visible at the top, was placed in hollow blocks, which were then filled with mortar. Mortar and bricks observed near the base of the minaret were of good quality.

FIGURE 58 When the masonry panel in the entrance structure of Yeni Mosque cracked diagonally, this light reinforced concrete column cracked with it, its stiffness and strength having no noticeable influence on the behavior of the wall. This is in contrast with the performance of the heavy columns supporting the roof, shown in the previous figure.

FIGURE 59 This 20-foot high bank of lacustrine clay with thin gravel lenses at a construction site on the west side of Burdur, undercut in some places, has stood for nine months with only small falls of earth. Soil everywhere observed in the Burdur region was firm, and no damage was attributed to soil failure.

FIGURE 60 Burdur's new 5-story reinforced concrete hospital had every column in the first story broken in flexure, leaving the building slightly displaced in the longitudinal direction. The two-story reinforced concrete framed laundry building, on the right, had only minor masonry cracking on one end wall. No damage was observed on the concrete block wall in the foreground.

FIGURE 61 A closer view of the south end wall of the hospital showing the columns to be relatively weaker in the longitudinal direction of the building. The furthest corner is completely fractured, and has begun to fall away from the structure.

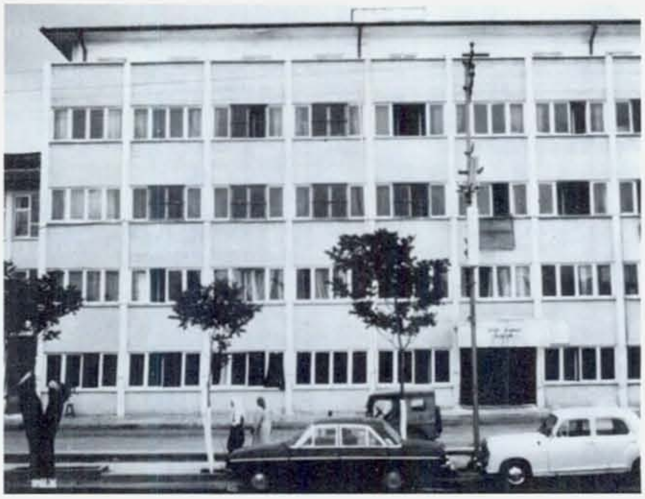


FIGURE 62 A front view of Burdur's hospital, showing permanent displacement to the right in the lowest story. The structure on the left is a second and third floor passageway to an older masonry building, which was severely cracked.

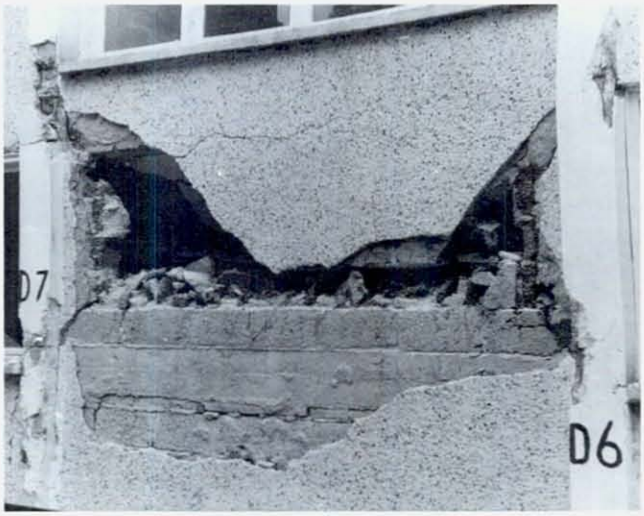


FIGURE 63 Column damage in the rear of the hospital. Most columns fractured at the top and bottom of window openings, being relatively fixed by concrete spandrels and cinder block walls above and below these openings.
(Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 64 A close-up of column damage at the rear of the hospital. Concrete was rather soft to a knife point, but no honeycomb was evident. The small column dimensions in the longitudinal direction of the building raise the suspicion that earthquake forces in the longitudinal direction were not considered in the design.

FIGURE 65 The north end wall of the hospital, front wall to the right, with a front column exposed. Note that the diagonal crack in the cinder block wall continues through the column. The outside faces of the cinder blocks have broken off and fallen with the exterior plaster. The white columns on the left support a passageway to an older masonry building.

FIGURE 66 Under construction, across the street from Burdur's hospital, is this 3-story school, of rather common design in Turkey. Every exterior column, between the top of the foundation wall and the bottom of the first floor, was shattered, causing the building to settle slightly. There was also minor damage to brickwork at roof level and in the first story. Note the chimneys standing in the background.

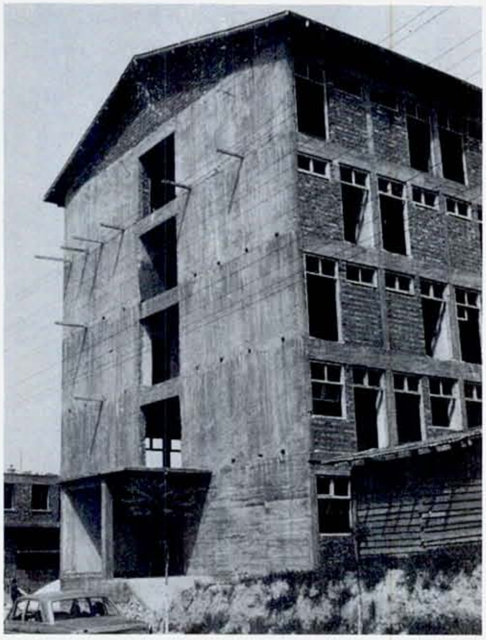
FIGURE 67 A close-up showing shattered columns, and some cracking of brickwork. Interior columns in the basement were free to deflect over their entire height, whereas the exterior columns were greatly restrained by the heavy basement walls. This great difference in stiffness resulted in all the lateral load being resisted by the exterior columns, and consequently suffering all the damage. Note that the columns are weaker in the longitudinal direction of the building, but column damage appears to be caused chiefly by motions in the transverse direction. Plans and additional photographs of this building are shown in Reference 12.
(Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 68 A close-up of the nearest corner column appearing in Figure 66. Additional column ties, more strongly anchored - perhaps by welding, would have been required to prevent this failure.

FIGURE 69 Another corner column at the top of the foundation wall in the new Burdur school: heavy beams not tied together, permitting concrete to be lost; a laterally weak column insufficiently tied; and poorly compacted concrete. A designer might have assumed that the foundation walls would brace the column and prevent failure, but the walls are of no help against forces directed toward the outside. In hindsight, a better design would be to rest the first floor slab directly on the foundation walls, providing a large area for the transfer of horizontal forces. (Photograph courtesy of Prof. Asim Yeğinobali)

FIGURE 70 Another corner column in Burdur's new school building, across from the hospital. Would bars in the spandrel beams extending around the corner have prevented this failure, or would such additional reinforcement simply lower the point of failure to just below the beams? (Photograph courtesy of Prof. A. Yeğinobali)

FIGURE 71 Just a few hundred feet from Burdur's badly damaged hospital and across the street from the new school building shown earlier, stands the Medical Technology School under construction. Workmanship and concrete were of average quality, and exterior columns were weaker in the longitudinal direction of the building. The structure had shear walls at each end, and also midway between the ends, but no longitudinal resistance other than the columns. Some masonry wall panels cracked, but structural damage was slight.



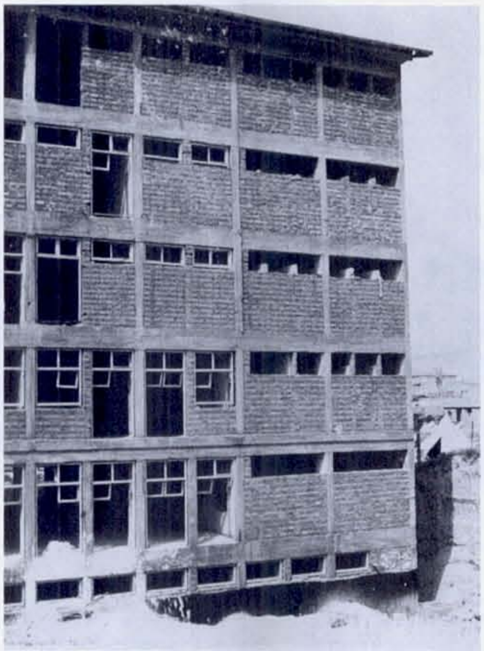


FIGURE 72 Several brick wall panels unattached to the structural frame fell out in the Medical Technology School, but had been replaced by the time this photograph was taken. There were very few instances of panels falling out in Burdur, even though in other buildings many panels were heavily cracked. This building, like the school across the street, had exterior basement columns fixed by basement walls over most of their height, but in this case there was no damage to them. Note the poor placement of concrete in the corner column.

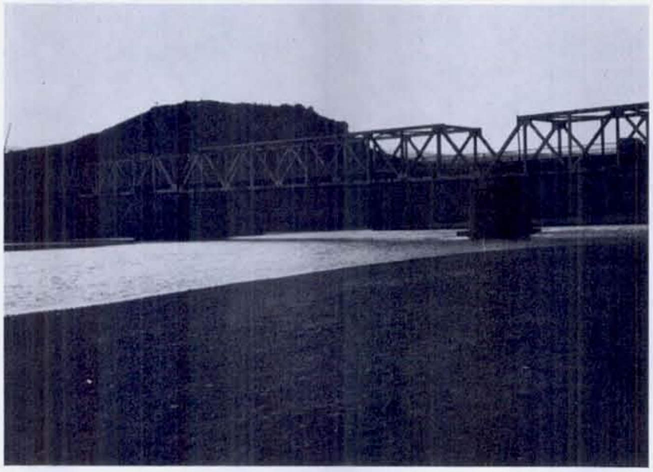


FIGURE 73 Looking upstream (north) at the steel bridge across the Murat River, 17 km SE of Bingöl, near Genç. Spans are numbered from left to right as 1, 2, 3, and piers as 1, 2. Pier spacing is 55 meters. The right end of each span is anchored so as to permit rotation only, whereas the left end of each is on rockers, which permit some longitudinal movement, but which are unstable, as shown in the following figure.

FIGURE 74 Rocker supports on the west end of span No. 3. This pier (No. 2) apparently shifted to the left (east) by about 15 cm, causing the relative displacement shown. The rockers did not fall completely because of restraining knobs on the base plate, but are obviously not now supporting the span. It is probably supported by interference of the bridge structure with span No. 2. The fixed support of the east end of span No. 2 pulled it to the east when the pier shifted, causing the railing to buckle (next figure) and pulling the span completely off its rocker support on pier No. 1. Sideways movement of some 20 cm of span No. 2 permitted the rockers to slide completely off the base plate on pier No. 1, dropping the end of the span 22 cm. The knife in the figure is 8.5 cm long. The need for bridge bearings which can accommodate pier displacements is obvious.

FIGURE 75 The west end of span No. 2 on top of pier No. 1, looking downstream. Sideways displacement of the span permitted the rockers to fall completely off the pier, dropping the span 22 cm vertically onto its base plate. The displacement here is about 20 cm downstream and 12 cm to the east.

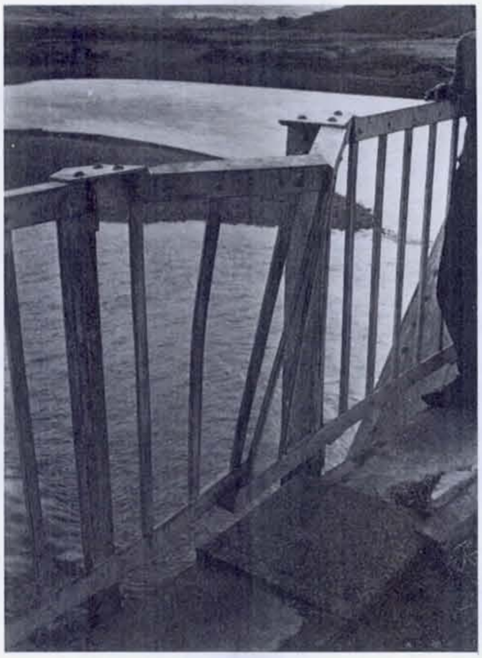


FIGURE 76 Looking downstream (south) at the buckled railing, span No. 3 on the left, span No. 2 on the right. Span No. 2 was dragged into span No. 3, which is fixed to the east abutment, by the shifting of the pier below.

FIGURE 77 The east abutment, showing the end of span No. 3. The facing stone has been broken away to permit inspection of the structural damage. The horizontal failure plane in the concrete appears to be a construction joint. Consideration should be given in design to the possibility of construction joints in piers having to withstand lateral as well as vertical forces.

FIGURE 78 Looking south at one half of the 5-span concrete bridge across the Göynük River at Köprübaşi, 10 km east of Bingöl. An extension of the line of the 8 km earth crack in the Göynük River bottom passes near here, but no crack was actually observed at this location. The center span and the end span both are continuous across their piers to support a simple span in the second bay from the abutment, the joints of which are visible at deck level. Pier spacing is about 24 meters.

FIGURE 79 The south side of the bridge, showing lateral movement of the simple span relative to the adjacent continuous spans, and failure at the tops of the piers due to sideways force from the superstructure. The nearest pier here is the leftmost pier in the previous figure.

FIGURE 80 Damage to the second pier from the west abutment and to the junction of the simple span with the central continuous span. The cause of the large crack near the bottom of the pier is not known.

FIGURE 81 Damage to the south roller support for the simple span, which rests on the overhang of the central continuous span. Only the two outer girders carry the reaction. The beam which distributes the loads from the inner girders to the outer girders can be seen faintly under the deck. Note the concrete cracking in the overhanging lip of the simple span.

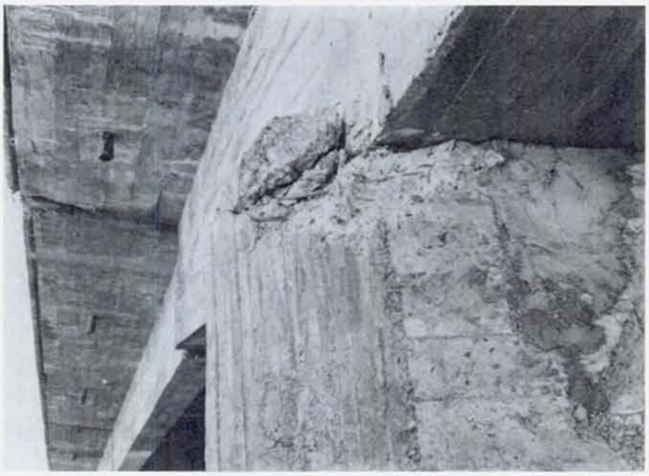


FIGURE 82 A close-up of damage at the top of the westmost pier. Note the poor placement of concrete and the patching. Diagonal steel extending into the shoulder at the top of the pier would have increased its strength.

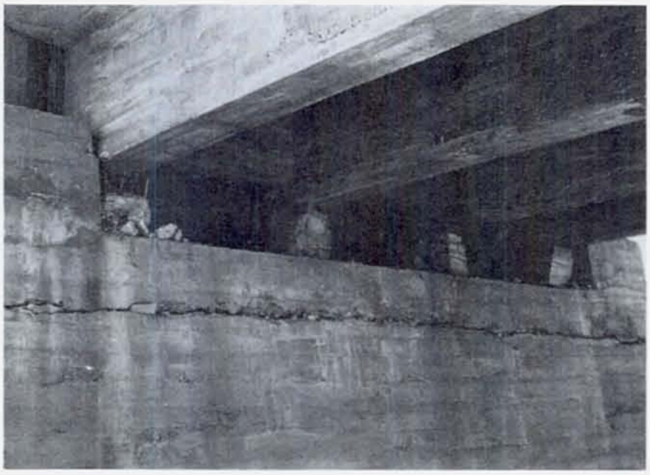


FIGURE 83 The west abutment was severely cracked, probably along a weak poor joint. The blocks under the girders, intended to provide a sliding joint, were rotated and badly disintegrated by the earthquake, almost permitting the bridge to drop unevenly on the abutments.

FIGURE 84 On the east edge of Bingöl stands a settlement of 88 houses recently built by the Ministry of Reconstruction and Resettlement for residents of Bingöl living in a landslide area. The plain shown slopes to the rear to the Göynük River, about 6 km away, along which it is believed faulting occurred. Approximately 1 km to the right of this project, on the same plain, lies a military post which suffered heavy damage to reinforced concrete buildings. No damage at all was reported to these settlement houses.

FIGURE 85 A closer view of the undamaged resettlement houses. The houses are of masonry, contain 55 m^2 gross area, and are on lots of 450 m^2. They cost $1,300, payable over a 20-year period with no interest charge. Water piped to a house costs $35 extra, and electric service is $40 extra. The chief complaint voiced by the owners of the houses is their small size. One resident is seen on the roof of an addition he is just completing. The complete absence of damage suggests that ground motion here was not as strong as in surrounding areas.

FIGURE 86 Buildings in Bingöl of prefabricated wall panels and roof trusses to be used as offices for resettlement construction. The walls consist of a 3-cm exterior layer of cement-asbestos, 5-cm of fiber glass, and an interior surface of 1-cm wood chip board. The walls are attached to a concrete floor slab by bolting to punched galvanized steel angles. This type of building has been suggested as housing for villagers, but it is doubtful if it would prove warm enough for Bingöl's cold winters (sometimes as low as -30°C) or sturdy enough to stand up under the rough usage conditions of village life.

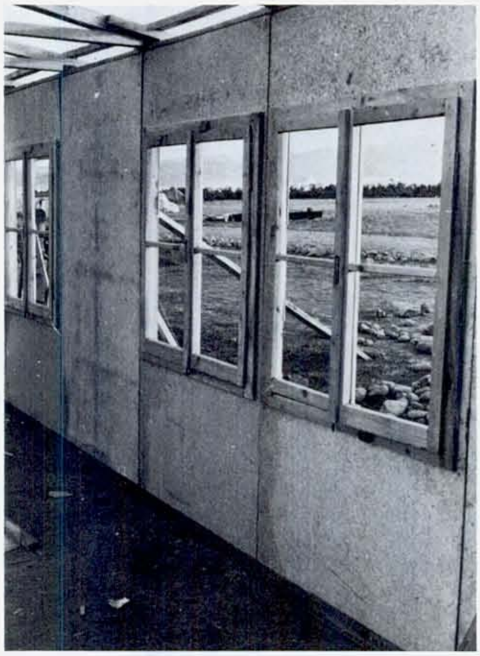


FIGURE 87 Interior of a prefabricated building being erected in Bingöl.

FIGURE 88 Machinery is scarce and manpower plentiful in most of Turkey. Here men mix and place concrete by hand for floors of prefabricated buildings in Bingöl. Laborer's wages were about \$1.75 per day at the time of this report.

FIGURE 89 A cinder block manufacturing operation in Burdur. The blocks, selling for five to seven cents each, contain little cement and can withstand only very low stresses, but are quite suitable for partition walls.

FIGURE 90 A brickyard in Genç, near Bingöl. Mud, soaked for 12 or so hours, is brought to the man in the pit who fills the molds, using fine sand to prevent the mud from sticking to the molds. The bricks are dumped on the ground for air drying and later piled into small stacks. As shown in Figure 91, a large burning stack is constructed of air-dried bricks, with finely crushed coal sprinkled between layers of bricks, and then plastered over with mud, ignited, and left to smolder for 15 or so days. Bricks made in this manner are soft and relatively weak. Sometimes the bricks are roasted a second time to improve the quality.

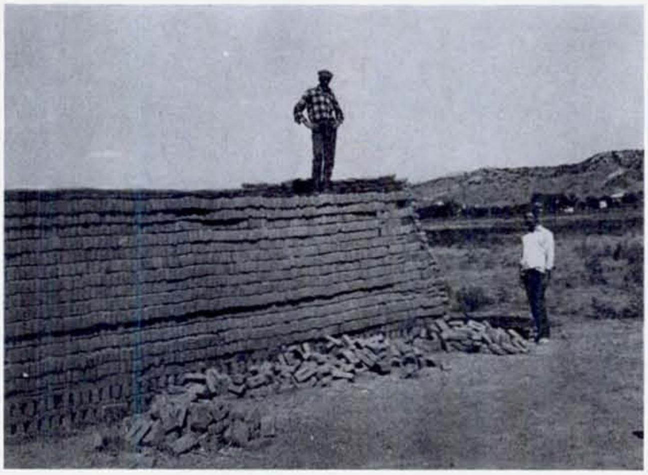


FIGURE 91 A roasting stack being constructed of air-dried bricks. Thin layers of coal can be seen between some of the layers of bricks. These bricks sell for about one cent each in the brickyard.

FIGURE 92 Poplar trees in a government planting in Yaziköy, Burdur district. In Turkey the poplar is a fast-growing, widespread tree planted by farmers along the borders of fields and ditches, and by the government in plantings like this. In eastern USA, a poplar will grow four to five feet in height and add one inch in diameter per year. The wood is suitable for house framing, but the great lack in Turkish villages is power saws to produce properly sized and squared lumber at reasonable cost.

FIGURE 93 This structure, erected in Bingöl after the earthquake, suggests a possible construction type for villagers and others who build their own homes. The columns are 10-cm square, and insulation consists of small pieces of mud poured into the wall voids as the lath application proceeded upward. Plastered inside and out, this structure would be weathertight, moderately warm, and safe during an earthquake. The major cash outlays would be for nails, corrugated steel roofing, and the sawing of the lumber.

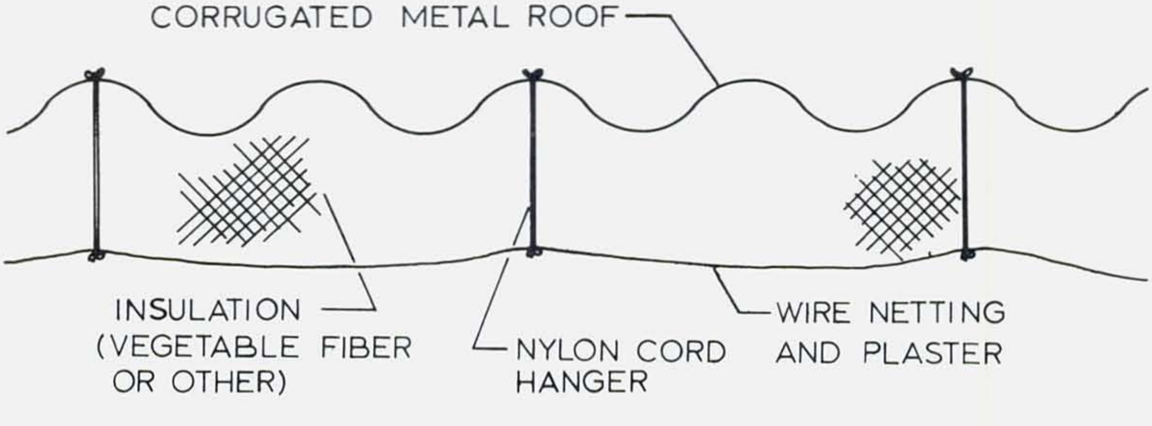


FIGURE 94 Cross section of suggested lightweight roof to replace mud roofs.