Abstract— Even though 92% of the total area of Turkey lies within seismic zones, earthen construction is very common and widespread throughout the country. Ever since construction materials are industrially manufactured, earthen construction technology is not in the scope of curriculums and research fields. Therefore, earthen buildings are often constructed by people with little technical knowledge of the material and existing earthen buildings are often insufficiently maintained. However, when used as a building material, the contribution that earth makes to a healthy environment is undeniable. Istanbul Technical University, which has been carrying out research projects on earthen construction material since 1978, has determined that earth can be stabilized with gypsum and lime resulting in improved durability, physical and mechanical properties with a compressive strength of 2-4 N/mm². This combination is referred to as “Alker.” There are Alker Case-Study buildings in use, with the experience since 1983.

This paper examines conformity of 2nd Case-Study Building, constructed with alker at 1995, with Disaster Code’97 issued by the Turkish Ministry of Public Works and Settlements.

Index Term— Alker; Disaster Code; Earthen Construction; Gypsum stabilisation

I. INTRODUCTION

When a region experiences a damaging earthquake, people begin to seek alternative structural systems and construction materials. In the Kocaeli earthquake (1999) in Turkey most of the damage was to reinforced concrete buildings, while the Afyon earthquake (2002) affected a region dominated by earthen construction. In fact, each type of construction functions well in terms of load-bearing and stability if it is carried out with the appropriate technology for the particular material in use.

Manufacturers of new construction materials and systems, together with schools of engineering and materials science have instituted massive changes in building construction in a relatively short historical time [1]. Particularly in Turkey reinforced concrete construction has rapidly displaced traditional building, evolving over generations and throughout the history. Traditional materials cannot keep pace with current legal requirements and market demands, without research or training support. Earthen construction technology requires efforts in terms of seismic reliability. With adequate interest in research, it is possible to improve the performance of unfired clay as a building material so that it can be accepted by the building industry as a modern material. Research carried out by the Architectural Department of Istanbul Technical University on stabilizing earthen construction material with gypsum: known as ‘alker’[2], and has succeeded in producing an improved construction.

II. RESEARCH METHODOLOGY

Because of the unpredictable nature of earthquakes it is impossible to protect buildings completely from the seismic risk [3]. The aim of the study is to examine the earthquake resistance of alker building and to show how alker building technology can meet the requirements of Turkish Disaster Code’97 [4] in relation to housing projects in seismic zones. Using the improved mechanical and physical properties of “alker”, three separate case-study buildings have been constructed over different time periods. In this study seismic reliability, which has been investigated with “Micro Tremor Test” [5] applied on the 2nd Case-Study Building, will be summarized. Then, design features of Case-Study Building will be presented and evaluated according to specific details of ‘Disaster Code’97 – Guidelines for Construction in Disaster Zones’ as prepared by the Turkish Ministry of Public Works and Settlements.

III. ALKER TECHNOLOGY

Lack of training and experience in earthen construction is one of the main reasons for the poor quality of earthen buildings. Due to poor traditional skilled workmanship the quality of earthen construction has decreased both in terms of comfort and safety. As a result of the research conducted by Istanbul Technical University (ITU) since 1978 it has been found that the mechanical and physical properties of earthen material are enhanced by stabilizing with gypsum. In particular, heat resistance and durability are relatively high in gypsum-stabilized earthen material, especially in conditions where water is present.

Conformity of Alker (Gypsum Stabilized Earth) Construction with ‘Disaster Code 97’ in Turkey, Bilge İŞIK, Dr., was with Istanbul Technical University, Istanbul-TURKEY. She is now with the Department of Architecture, Cyprus International University, N-Cyprus (phone: +90-532-767-5356; fax: +90-212-266-0279; e-mail: bilgeisik@superonline.com).

TABLE I

<table>
<thead>
<tr>
<th>Physical, Mechanical Properties of Alker [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit weight</td>
</tr>
<tr>
<td>Shrinkage</td>
</tr>
</tbody>
</table>
Compressive strength 2.0-4.0 N/mm² [5]
Shear strength 0.9-1.3 N/mm²
Water absorption very low
Long term water exposure (except direct rainfall) no erosion
Heat transfer value λ 0.4 - 0.5 kcal/m²°C
Specific caloric value 1.0 kJ/kgK

Compressive strength also by 2.0-4.0 N/mm²
SIA DO 111 [4] and [5]

A. Proportioning and Properties of Alker

Alker Construction Material is composed of 10% gypsum, 2\% lime and 20-22\% water in respect to the dry weight of soil. To delay setting time, lime is added to the water before the gypsum. The resulting liquid is poured into the soil and mixed manually or by machine. The alker mixture is then placed into brick size moulds and compacted or injected directly into a wall form.

| TABLE II |
| PRACTICAL MEASURES OF INGREDIENT OF ALKER |
| BY WEIGHT OF SOIL |

<table>
<thead>
<tr>
<th>Soil</th>
<th>Water</th>
<th>Lime</th>
<th>Gypsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 kg</td>
<td>20%</td>
<td>2%</td>
<td>10%</td>
</tr>
<tr>
<td>18-20 kg</td>
<td>2 kg</td>
<td>10 kg</td>
<td>4 shovel full</td>
</tr>
<tr>
<td>2 full wheel barrow</td>
<td>1 bucket full</td>
<td>1 shovel full</td>
<td>4 shovel full</td>
</tr>
</tbody>
</table>

Earth used for alker is different from the earth used for traditional earthen building material. Clay is the binding component of traditional earthen construction. The required binding property can only be achieved if earth has 30-50\% clay content. However, the addition of gypsum makes a significant contribution to binding, so earth with 8-10\% clay content is sufficient for alker composite. Excessive clay content increases shrinkage, while insufficient clay content reduces binding.

Owing to its lower clay content, the earth used in alker technology is much more readily available than the earth required for traditional earthen construction. In fact, it is often the case that earth obtained in excavation for the foundations of a building can be used as construction material. The presence of lime and gypsum in the mixture dramatically reduces the time spent for mixing, molding, compacting, and turning out from moulds. Gypsum reduces the level of shrinkage in the building material while alker possesses durability required for load-bearing wall construction. Additionally, alker is more porous and lighter than unstabilized earthen materials because the gypsum sets before the clay dries (Table I). This porousness in turn provides better heat insulation. The compressive strength of alker is 2-4N/mm².

B. Producing and Design in Alker Technology

Alker is a earthen construction material used in bearing wall buildings. Alker walls can be built with blocks, or the material can be compressed, rammed or injected into a wall form. The moulds and machinery used in concrete technology can be used for alker, which is an appropriate building system for both ‘owner-built’ residential housing and mass housing operations as well.

The 2nd Alker Case-Study Building was designed to demonstrate the applicability of alker to mass housing projects. Alker mixture is poured directly into a PERI mould (an industrial product used in concrete construction) and the walls are compacted using a Wacker Compressor, Hilti Hammer, or ram. A layer of welded galvanized steel mesh is located horizontally through the walls at 60cm intervals. The mesh has 8x3 cm holes and steel bars are 3 mm thick. Reinforcement of the alker wall reduces shrinkage as the wall dries out after construction and responses to tensile forces occurring due to seismic loads.

The top and bottom of an alker wall should be bounded with a reinforced tie-beam. Load-bearing walls should stand on continuous foundations. A one-storey house should have load-bearing walls of at least 30 cm thickness. The external walls should be 45 cm thick to postpone heat transfer. The flooring can be constructed as a rigid diaphragm out of wood or steel, or reinforced concrete. The roof can be flat or pitched.

IV. SEISMIC MEASURES FOR LOAD-BEARING SYSTEM OF ALKER CONSTRUCTION

Load-bearing walls should be able to sustain forces caused by horizontal acceleration during an earthquake. As vertical loads increase, the momentum caused by horizontal forces is reduced, thereby contributing to stability. This behavior of load-bearing walls is an advantage for construction with earthen material.

The vertical load of a building compounds horizontal forces on load-bearing walls. Horizontal forces applied to load-bearing walls cause diagonal shear cracking. The horizontal forces caused by an earthquake can be calculated using the load of the building itself and the load carried by the building. According to the SIA (Swiss Construction Engineers and Architects Association) [6] the horizontal force is 6.9\% of the vertical load (this figure is 10\% according to New Mexico Code) [7]. Typically, 18-25\% of the plan of a load-bearing wall building is covered by wall thickness. In brief, during an earthquake 6.9-10\% of building load acts upon 18-25\% area of the total building plan in the form of horizontal forces. This clearly illustrates the advantage of thick load-bearing wall earthen constructions during earthquakes. The ratio of external wall thickness to wall height in alker construction has been applied as 1/5 and internal 1/10 [7]. Usage of horizontal reinforced tie beams and diaphragm slabs contribute to the stability of the system.

Not only the mechanical properties of the material but also the design dimensions of load-bearing walls are important factors in the load-bearing capacity of alker buildings. The necessary dimensions for load-bearing walls are stipulated in “Disaster Code’97” in the section entitled ‘Bearing Wall Construction’.
V. ALKER 2\textsuperscript{nd} CASE STUDY BUILDING, 1995

Within the “Alker Case-Study Project TUBITAK, INTAG and TOKI 622" (The Scientific and Technological Research Council of Turkey; Construction Research Group; the Housing Development Administration of Turkey, respectively) the Case-Study Building II (Fig. 1) was constructed in 1995 \cite{8}. 12 years after the first alker case-study project. It involved the study of mechanization and standardization possibilities in alker construction.

The Case-Study Building II project consists of an entrance hall, a bathroom, a kitchen and 3 other rooms (Fig. 2). The reinforced concrete tie-beam running round the tops of the alker walls is connected with reinforced concrete slab. Inclined roof is covered with corrugated Ondulin and ceramic tiles.

A. Seismic Risk Studies for the 2\textsuperscript{nd} Case-Study Building

Earthen buildings are widespread throughout the world and face seismic risks. Similarly, earthen construction is commonly used for buildings in Turkey although 92\% of the total area of Turkey lies within seismic zones.

There are 3 main factors, which determine the behavior of buildings during earthquakes:

a) Ground effect
b) Construction material
c) Structural system (design specifications)

Disaster Code 97 dwells mainly upon structural system and construction material.

B. Micro-Tremor Test on the 2\textsuperscript{nd} Case-Study Building

Studies continue to understand and improve the earthquake behavior of load-bearing alker constructions. One of these studies is the measurement of “Micro Tremors” performed in 1999 on the Case-Study Building II (Fig. 1, 2). Microtremors studies can give useful information on dynamic properties such as existed place, building type, dimensional scale or number of stories etc. According to these studies both fundamental periods in these two directions are found to be 1.56 Hz. These results are given in Fig. 3. With this period the spectrum coefficients on normalized spectral curves are calculated as 1.36 and 1.71 for soil conditions Type I and Type II respectively which is shown in Fig. 4. The suitability of construction-ground interaction has been tested \cite{5}. The equivalent seismic load is calculated as 51\% of the total weight of the building. A simple calculation for shear average stress in the walls is obtained as

\[ \tau_{\text{average}} = 0.005 \, \text{MPa}. \]

This value is less than

\[ \tau_{\text{material}} = 0.175 \, \text{MPa}. \]

C. Conformity of Case-Study Building with Disaster Code’97

Case-Study Building II has experienced the earthquake of 7.4 on the Richter Scale (Kocaeli 1999) after constructed at 1995. No damage or crack has been observed at earthen building, although some of the University buildings were taken out of order. Therefore it is significant to compare the design features of the Case-Study Building in accordance with the guidelines of Disaster TR-Code’97.
The dimensions of the span are small and wall length is not less than 0.25 m/m² when the total length of load-bearing walls is considered.

Maximum length between the supports of load-bearing walls is approximately 4.5 m.

As seen in Figure 1, the distance between corner and wall opening is not less than 1.0 m.

The load-bearing wall segments between window or door openings are nearly 1.0 m. Since the load-bearing wall segments between window or door openings are approximately 1.0 m, dimensions of vertical
ties have not been considered.

The wall segment from axes of intersections to wall openings complies with the value above.

Door openings are not more than 100 cm wide but can extend up to the concrete tie-beam giving a height of up to 240 cm. Therefore no lintels are needed. Window openings are 90x140 cm on average.

VI. CONCLUSION

Earth, the most commonly used construction material in the world, has undergone a revival in the industrialized world due to its benefits for human health and ecology. Despite its low strength, if appropriate techniques are applied, earthen material maintains its load-bearing capacity during earthquakes and loss of life can be prevented even when cracking does occur. Istanbul Technical University (ITU) has been working on this appropriate technique since 1978. The following criteria have been considered in case-study buildings constructed by ITU since 1983 with alker, which has a compressive strength of 2-4 N/ mm²:

a) During an earthquake horizontal force affects bearing walls with 6.9%-10% of vertical loads.

b) Earthen load-bearing walls account for 15%-25% of the total plan area of an earthen construction and respond to horizontal forces during an earthquake.

c) As vertical load increases, the horizontal vector of the forces is reduced, decreasing collapse risk.

d) When the ratio of wall thickness to wall height is between 1/5 and 1/10, stability of the building can be achieved.

The Case-Study Building II constructed in 1995 aimed to determine the seismic reliability of alker buildings when subjected to horizontal forces. This reliability and its consequent conformity with Disaster Code97 were established on the basis of the following structural requirements:

a) T and L wall junctions
b) Ratio of wall thickness to load carried
c) Ratio of wall thickness to wall height
d) Ratio of continuous wall to wall openings
e) Tie-beams above and below the walls

Studies on the earthquake reliability of alker load-bearing wall construction are continuing and their progress can be followed at www.kercip.org

The Alker Case-Study Building II, constructed in 1995, showed good performance in the 1999 Kocaeli Earthquake. While buildings in the University campus cracked slightly, the alker construction sustained without damage.

ACKNOWLEDGMENT

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REFERENCES


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