THE WEB-BASED WORLD HOUSING ENCYCLOPEDIA: A RESOURCE ON ADOBE CONSTRUCTION IN HIGH SEISMIC RISK AREAS OF THE WORLD

Svetlana Brzev\textsuperscript{1} and Marjorie Greene\textsuperscript{2}

ABSTRACT
Recent devastating losses in earthquakes to housing around the world highlight the need to share information on building construction practices and strengthening technologies. The Earthquake Engineering Research Institute and the International Association for Earthquake Engineering have an ongoing Internet-based project called the World Housing Encyclopedia (WHE) that provides a framework for sharing such information globally (www.world-housing.net). The purpose of the WHE is to develop a comprehensive global categorization of characteristic housing construction types presented using a standardized report format. Each housing report covers relevant aspects of housing construction including architectural features, the structural system, seismic deficiencies and strengths, performance in past earthquakes, available strengthening technologies, building materials used, the construction process, and the availability of insurance. In addition to the text and numerical information, several illustrations (photos, drawings, sketches) are also included in each report. As of this writing, the encyclopedia contains over 100 detailed reports on housing construction from 36 countries, including 11 reports on adobe construction from the following countries: Argentina, El Salvador, India, Kyrgyzstan, Malawi, Peru, and Iran. The information provided in the encyclopedia is useful to local, national and international public and private organizations and individuals concerned with improving the seismic resistance of a region’s housing stock. This paper offers an overview of the encyclopedia, and provides a comparison of adobe housing construction from different countries featured on the web site.

INTRODUCTION
The Earthquake Engineering Research Institute and the International Association for Earthquake Engineering have an ongoing web-based project called the World Housing Encyclopedia (WHE) that uses the Internet and modern database technology to share information globally on housing construction (www.world-housing.net). The purpose of the encyclopedia is to develop a comprehensive global categorization of characteristic housing construction types presented in a report using a standardized format (Brzev et al., 2004). All relevant aspects of housing construction are covered by the report, such as socio-economic issues, architectural features, the structural system, seismic deficiencies and earthquake-resistant features, performance in past earthquakes, available strengthening technologies, building materials used, the construction process, and insurance. In addition to the text and numerical information, several illustrations (photos, drawings, sketches) are also included in the report.

All reports comprise a searchable database of global housing construction. As of this writing, there are 116 reports from 36 countries in the database; out of these, 100 reports have been completed and can be browsed on the web site, while the remaining reports are in different stages of completion. The distribution of housing reports by continent available in the database

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is shown in Figure 1. For some construction types, this is one of the few, if not only, places where such detailed information is available in English. The framework created by this project provides an inexpensive and effective way for earthquake professionals in many countries to share knowledge on construction practices and retrofit techniques. This project has been primarily a volunteer effort, bringing together over 180 prominent engineers and architects from 47 countries, and providing them an opportunity to share knowledge about housing in their own countries, and to communicate with each other, as reviewers and as users of the data provided on the encyclopedia web site. This paper provides an overview of the web site and its main features.

![Pie chart showing distribution of housing reports by continent](image)

**Figure 1. Distribution of housing reports by continent (March 2005)**

The first hard-copy project publication (Brzev and Greene, 2004) was launched in August 2004 during the 13th World Conference on Earthquake Engineering held in Vancouver, Canada. The publication is intended to provide an overview of the project, for users who want to review at a glance the countries and construction materials that are described on the web site. This publication also includes summaries of the major building technologies found on the web site, including adobe, stone, brick masonry, confined masonry, reinforced concrete frame and shear wall construction, precast concrete construction, advanced technologies, timber construction, and vernacular construction. Following each of these summaries are the one-page excerpts from each of the reports on the web site, containing the summary of the construction type and several representative figures. A companion CD including the full contents of all reports available as of May 2004 is attached.

In March 2005, the project launched a free electronic newsletter to stimulate worldwide discussion about ways to address the growing earthquake risk associated with housing. This quarterly newsletter – to be sent out in March, June, September and December – will feature important news related to earthquake risk reduction initiatives related to housing around the world.

**MAIN FEATURES OF THE WHE WEB SITE**

**World Map**
The interactive world map enables the users to identify all reports from a certain country. The user clicks on a continent (s)he is interested in and is given a listing of all countries and regions
there. When the cursor passes over a country, it turns red and the number of reports available for that country is indicated in the corner. The user can then click on a country (either on a map or by clicking on its name listed on the screen) and view all available reports from that country.

About the Project
This section of the site contains the project overview, roster of project contributors and the Editorial Board. Initially, in the period 2000-2002, the project was managed by a nine member international steering committee. In 2003, the project made a transition to an Editorial Board that oversees its development. The Editor-in-Chief, six regional editors and four Editors at large are in charge of managing the project, providing overall direction and developing new initiatives. Each regional Editor coordinates project development within a region and/or continent (Asia, Africa, Europe, North America and Australia/Oceania). The Board currently consists of 27 members from 19 countries. Members of the Editorial Board have responsibility for recruiting participants from new countries and reviewing the newly submitted contributions.

Country-Based Information
Once a country is selected, the user is able to view country-based information. The seismic hazard map for the country appears (adapted from the Global Seismic Hazard Assessment Program (http://seismo.ethz.ch/GSHAP/). When the user scrolls down, a table containing the listing of specific reports available for that country appears. General country-related information, including documents and web links related to housing and seismic risk information, is also available for most countries. Some typical statistics are also included, such as the size and general rate of increase in urban/rural housing stock in the country and the density of urban/rural housing.

Search the Database
One of the strengths of the encyclopedia database is the ability to compare information across countries and construction types. Searches can be conducted by continent (geographical distribution) by various common features for housing construction types: building function, urban vs. rural construction, period of practice, economic level of inhabitants, load-bearing structure, building material, number of stories, seismic vulnerability rating, seismic strengthening technologies, engineered vs. non-engineered construction, building codes and standards, and earthquake insurance. Alternatively, if a specific continent is not indicated, a global search can be performed by checking one or more search parameters. For example, a search of building function would enable the user to identify all single-family housing construction types in Asia, or all multi-family housing types (apartment buildings) in Europe. There are a number of reports on adobe construction, as shown in Table 1. By using the search capabilities of the encyclopedia it is possible to quickly see typical adobe construction methods and strengthening approaches, if any, across countries as diverse as Peru, El Salvador, India and Iran.
Table 1: Examples of reports on adobe construction

<table>
<thead>
<tr>
<th>Country</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Traditional adobe house with reinforcement (Rodriguez et al 2002)</td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td>Adobe house (Loaiza et al 2002)</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>Traditional rural house in Kaabb region (bhonga) (Choudhary et al 2002)</td>
<td></td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>Houses with mud walls and timber roofs (Uranova and Begalev, 2002)</td>
<td></td>
</tr>
</tbody>
</table>

**Tutorials and General Resources**

The web site also has a growing resource section, containing relevant publications and web links mainly related to the nature of earthquakes, the earthquake behavior of buildings, and the performance of various construction practices in earthquakes. In addition to these links, project participants are currently working on a series of tutorials on various construction materials.

The first tutorial, on adobe construction (Blondet, Villa Garcia, and Brzev, 2003), is an interactive online resource on adobe construction and techniques for improving seismic
performance of this vulnerable construction type widely used in many earthquake-prone areas of the world. The tutorial begins with an introduction on adobe construction, followed by the description of typical patterns of earthquake damage. This document discusses the improved earthquake performance of new adobe construction, as well as the strengthening of existing adobe buildings. The most important factor for the improved seismic performance of adobe construction is to provide reinforcement to the walls. A ring beam (also known as a crown, collar, bond, or tie beam or seismic band), usually made of timber, ties the walls in a box-like structure and is one of the most essential components of earthquake resistance for load-bearing masonry construction. Additional wall reinforcement, made of any strong and ductile material, such as bamboo, reeds, cane, vines, rope, timber, chicken wire, barbed wire, or steel bars, should also be provided. Examples of seismic reinforcement for adobe buildings featured in the tutorial are shown in Figure 2.

Figure 2. Seismic reinforcement for adobe walls: a) crown beam made of eucalyptus trunks; b) tying of reinforcement.

The adobe tutorial contains several downloadable references (papers and manuals) linked to it and also a couple of video files showing the shake-table testing of adobe construction. The tutorial can be viewed or downloaded by clicking on “General Resources/Tutorials”.

The tutorial on confined masonry construction has been recently posted on the web site (Blondet, 2004), while the development of a tutorial on reinforced concrete frame construction with masonry infills is currently in progress.

HOUSING REPORTS
The project steering committee has developed a standardized report format that is used by project participants to describe individual construction types in their respective countries. Each report consists of over 60 questions, covering relevant aspects of housing construction e.g. architectural features, structural system, seismic deficiencies and strengths, performance in past earthquakes, available strengthening technologies, building materials used, the construction process, and insurance. Structural systems have been classified into 30 generic types, covering global housing construction made out of masonry, concrete, timber, and steel. An important feature of the report is that it is able to describe features of both nonengineered rural housing (e.g. adobe masonry) and urban highrises (e.g. concrete shear wall buildings, prefabricated concrete panel buildings, etc.). As of this writing, there are 67 reports describing engineered construction while the remaining 33 reports describe nonengineered housing construction practice. Using a standard form, participants are encouraged to contribute as many reports
describing various urban and rural housing construction types characteristic for their countries as possible.

Depending on the structural system and the country, each report contains unique information. However, the fact that participants all respond to a common set of questions makes it possible for comparison. The reports typically contain many illustrations, both photos and figures, that further describe the construction type.

Each housing report contains information in the following ten categories (sections): General Information; Architectural Features; Socio-economic Issues; Structural Features; Evaluation of Seismic Performance and Seismic Vulnerability; Earthquake Damage Patterns; Building Materials and Construction Process; Construction Economics; Insurance; and Seismic Strengthening Technologies. Examples of the selected sections are given below.

GENERAL INFORMATION
The general information section includes a summary of the housing construction type and information on the typical period of practice and regions of the country where such construction has been practiced. See Table 2 for examples from two housing types included in the encyclopedia.

Table 2: Examples of Construction Type Summaries

<table>
<thead>
<tr>
<th>EL SALVADOR</th>
<th>This housing type can be found in rural and urban areas. In rural areas, adobe houses are generally small in size, 5 x 6 m in the plan, having load-resistant walls made of adobe bricks between 0.3 and 0.5 m thick. Usually, they are single-family (5-person) houses. Wood planks that support metal sheets covered by tiles sometimes constitute the roof. In some cases, the roof can be a thatched roof supported on wood purlins. In urban areas, adobe houses are much bigger; they are one-storey structures and their plan dimensions are 15 x 30 m or larger. The wall thickness can easily reach 1 m and wall height can reach 3 m or more. In both the cases, the adobe housing type has performed badly in earthquakes. Its heavy roof sometimes can be its biggest weakness and its unreinforced walls make this house vulnerable to earthquake effects.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vivienda de adobe (adobe house) (Lopez et al. 2002)</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>INDIA</td>
<td>This is a typical rural construction found throughout India, except in the high rainfall areas in the northeastern part of the country. It is a single-family house, mainly occupied by the poorer segment of the population. The main load-bearing system consists of mud walls, which carry the roof load. In some cases wooden posts are provided at the wall corners and at intermediate locations. The wooden posts and walls are not structurally integrated, and therefore the loads are shared by the walls and the frame. There are very few openings (doors and windows) in these buildings. In rural areas there are usually no windows at all. In general, this type of construction is built by the owners and local unskilled masons and the craftsmanship is very poor. This building type is classified as grade-A (most vulnerable) per the IAEE building classification and IS Code 1893:1984. This is a low-strength masonry construction and it is considered extremely vulnerable to seismic forces.</td>
</tr>
<tr>
<td>Rural mud house with pitched roof (Kumar, 2002)</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>
STRUCTURAL FEATURES
The heart of the report and of the encyclopedia itself is the information describing the structural system. All housing types are classified into 34 structural systems (see Table 4.1 of the standard report). The prevalent building materials include concrete (9 systems), steel (5 systems), masonry (13 systems), and timber (6 systems). Breakdown of the housing reports based on the material of construction is shown in Figure 3. Structural systems characteristic for masonry housing construction include 13 different types of bearing wall systems: two types of stone masonry walls, four types of earthen walls, confined masonry, and three types of concrete block masonry walls.

![Figure 3. Breakdown of housing reports per building material (number of available reports indicated in the brackets).](image)

This section includes a description of the lateral load-resisting system and the gravity load-bearing structure, as well as tables identifying the structural system, type of foundation, and type of floor/roof system. In addition, participants provide information on typical plan dimensions, typical number of stories, typical story height, and typical span. Table 3 contains an example of this description from Slovenia.
Table 3: Example of Description of Structural System: Rubble-Stone Masonry House, Slovenia (Lutman and Tomazevic, 2002)

Figure A shows an isometric view of an older rubble stone masonry house typical for Slovenia. The lateral load-resisting system consists of exterior and interior stone walls. The walls are generally uniformly distributed in both orthogonal directions, and the building plan is generally regular (a typical plan is shown in Figure B). In general, the walls are not connected by means of wooden or iron ties. The thickness of walls varies from 40 to 70 cm, with spacing ranging from 3.0 m to 6.0 m. A typical wall section is shown in Figure C. The walls are supported by strip foundations made out of rubble masonry (or there are no footings at all). Lateral load transfer to bearing walls is accomplished through roof and floor structures.

The main weaknesses in this construction practice include: weak inner infill between exterior wythes of masonry, vertical joints between walls, and roof-to-wall and roof-to-floor connections.

EVALUATION OF SEISMIC PERFORMANCE AND SEISMIC VULNERABILITY
This section of the encyclopedia contains information on any seismic deficiencies associated with the construction type, as well as its earthquake resilient features and its performance in past earthquakes. The description is complemented with the illustrations, wherever appropriate. Table 4 illustrates the kinds of information provided on seismic features for adobe construction practices in India and Argentina.
Table 4: Example of Information Provided on Seismic Features

<table>
<thead>
<tr>
<th>Country and Construction Type</th>
<th>Structural Element</th>
<th>Seismic Deficiency</th>
<th>Earthquake Resilient Features</th>
<th>Earthquake Damage Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>India: Traditional Rural House in Kutch Region of India (Bhong) (Choudhary, Jaiswal, and Sinha, 2003)</td>
<td>Wall</td>
<td>Poor quality of construction materials (adobe blocks and mud mortar)</td>
<td>Excellent resistance to lateral loads due to the shell action of cylindrical walls.</td>
<td>Minor damage in the walls constructed with cement mortar and significant damage to walls constructed with mud mortar were observed after the 2001 Bhuj earthquake.</td>
</tr>
<tr>
<td>Argentina: Traditional Adobe House Without Seismic Features (Rodriguez, Yacante, and Reiloba, 2002)</td>
<td>Wall</td>
<td>Lack of connection between walls, Adobe block masonry simply laid on the ground without any foundation or plinth, Openings placed next to wall intersections, Wall openings exceed 30% of the total wall area.</td>
<td>Collapse of interior walls. Falling down of pieces and parts of adobe blocks from the middle of the face of the wall. Collapse of walls weakened at the base due to the water erosion. General cracking of walls. Damage on the upper corners of the openings. Lintel collapse. Loosening of plaster due to the lack of adhesion.</td>
<td></td>
</tr>
</tbody>
</table>

Section 5.3 of each report includes an estimate of the seismic vulnerability rating for the housing construction under discussion. The rating is determined according to the EMS scale (EMS, 1998). While many reports (39 in total) currently available in the database describe highly vulnerable construction (EMS vulnerability Classes A and B) that has performed poorly in earthquakes, such as unreinforced masonry construction and non-ductile concrete construction, there are also 19 reports describing earthquake-resistant construction (Classes E and F per EMS scale). Examples of earthquake-resistant construction range from engineered structures such as reinforced concrete shear wall construction in Chile (Moroni et al., 2002) and tunnel form construction from Turkey (Gulkan and Yakut, 2003) to vernacular construction such as the traditional timber house (yurt) from Kyrgyzstan (Begaliev and Uranova, 2002) and the “bhonga” construction from India (Choudhary, Jaiswal, and Sinha, 2003). It is believed that the users of the WHE can benefit both from the information on construction practices that have shown poor performance in past earthquakes as well as information on construction practices that have shown good earthquake performance.
EARTHQUAKE DAMAGE PATTERNS
The reports contain information on past earthquakes that have affected the construction type under discussion. For each of these earthquakes, a table lists year, epicenter, Richter magnitude, and maximum intensity (noting scales used). Additional comments discussing damage may also be included. Several illustrations of earthquake damage to a particular construction type are provided. It is believed that such illustrations are valuable for earthquake engineering professionals interested in comparative seismic performance of different construction types worldwide. The reports on housing construction affected by the 1999 Izmit (Turkey) earthquake, 1999 Chi Chi (Taiwan) earthquake, 2001 Bhuj (India) earthquake, 2003 Boumerdes (Algeria) earthquake and 2003 Bam (Iran) earthquake are included in the encyclopedia. Table 5 illustrates the kind of information provided in this section, in this case for adobe construction from Iran.

Table 5: Example of Earthquake Damage Patterns: Adobe House, Iran
(Mehrain and Naeim, 2004)

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Earthquake Epicenter</th>
<th>Richter Magnitude (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>Bam</td>
<td>6.6</td>
</tr>
<tr>
<td>1997</td>
<td>Ardekul</td>
<td>7.3</td>
</tr>
<tr>
<td>1990</td>
<td>Manjil</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Description of the earthquake effects: Iran has a long history of devastating earthquakes that have affected adobe structures. In the 2003 Bam earthquake, over 40,000 people died; in 1997 over 1,568 people died and in the 1990 earthquake in Manjil over 40,000 people died. In the Bam area, there have also been other significant earthquakes: in the Gisk-Zaran 1977 earthquake–665 people were killed; in the 1981 Golbaf earthquake–between 1,000 and 3,000 people were killed; in the 1981 Sirch earthquake–1300 people killed. Many people in Iran were killed in adobe structures.

BUILDING MATERIALS AND CONSTRUCTION PROCESS
Another section of the encyclopedia includes information on building materials and the construction process, including a description of the characteristic strength of the building materials and details regarding the construction process. Design and construction expertise is described, as are building codes and standards, building permits and development control rules, the role of engineers and architects, the phasing of construction, building maintenance, the process for building code enforcement and typical problems associated with a particular construction practice. Some reports contain very interesting historical information on building code enforcement. For example, a report on the historic braced timber frame buildings with masonry infill (known as “Pombalino” buildings) from Portugal describes the process of building
code enforcement after the catastrophic 1755 earthquake that struck Lisbon. “Beginning in 1758
and during the Marquês de Pombal’s governance, the penalty for failing to follow construction
rules was the demolition of the building by order of the king.” (Cardoso et al., 2003). Details of
the “Pombalino” building are shown in Figure 4.

![Figure 4. An early form of earthquake-resistant braced frame
collection in Portugal (Cardoso et al., 2003)]](image)

SEISMIC STRENGTHENING TECHNOLOGIES
This section includes a discussion on seismic strengthening technologies available for each
construction type. In some cases, no strengthening is needed or none has been tried; for other
construction types several strengthening techniques are available and are summarized in text and
through figures. One of the objectives of the encyclopedia is to share information related to
effective seismic retrofit technologies used for various construction types worldwide.
Technologies tested in real earthquakes have been identified and described whenever possible.
For example, reinforced concrete frames with masonry infills have been recognized as one of the
most vulnerable modern housing construction practices, and were affected by the 1999 Turkey,
1999 Chi Chi (Taiwan), 2001 Bhuj (India), and 2003 Boumerdes (Algeria) earthquakes. As of this
writing, the WHE contains 25 reports on moment resisting concrete frames, out of which 19
describe concrete frames with masonry infill. Table 6 illustrates some of the examples received
for reinforced concrete construction with masonry infills, along with some of the strengthening
options presented in each report.
<table>
<thead>
<tr>
<th>Country</th>
<th>Reference</th>
<th>Image 1</th>
<th>Image 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>(Gulcan et al., 2002)</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>Colombia</td>
<td>(Meja, 2002)</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>Cyprus</td>
<td>(Levtchitch, 2002)</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>Taiwan</td>
<td>(Yao and Sheu, 2002)</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
</tbody>
</table>

Table 6: Reinforced Concrete Frame Construction and Strengthening Strategies around the World
CONCLUSIONS
The WHE web site has received much attention and positive feedback from users around the world. It currently receives over 4,000 unique visitors per month (with over 9,000 unique visitors in March 2005), from insurers and risk modelers who use the information to refine their models to earthquake engineers and architects who use the information to improve their design and construction practice and academics who use the WHE as a learning resource for students. One of the real strengths of the WHE is the opportunity it provides users to easily compare construction approaches, materials and techniques across countries or construction materials. It is believed that this encyclopedia will contribute to global earthquake risk reduction by providing easy access to information on various housing practices, and by identifying good and bad practices influencing the seismic performance of a building.

The project continues to grow and new participants are welcome. In 2003, Farzad Naeim, one of the key members of the WHE project team, and instrumental in the development of the project web site with his colleagues from John Martin and Associates, decided to sponsor three annual awards ($1500, $1000, and $500) for the best contributions to the World Housing Encyclopedia. A report on adobe construction from Peru (Loaiza, Blondet, and Ottazzi, WHE Report 52) is among the winners for 2003.

Further information is available from the web site or by contacting Managing Editor Marjorie Greene at mgreene@eeri.org or Editor-in-Chief Svetlana Brzev at sbrzev@bcit.ca.

ACKNOWLEDGMENTS
This project is only possible because of the volunteer effort of all the contributors. See www.world-housing.net (About the Project) for a complete roster of project contributors. Special thanks are due to Farzad Naeim and the web site development team of John A. Martin and Associates, Los Angeles, USA.

REFERENCES


