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THE WEB-BASED WORLD HOUSING ENCYCLOPEDIA: HOUSING CONSTRUCTION IN HIGH SEISMIC RISK AREAS OF THE WORLD

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SUMMARY

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 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 format. The encyclopedia provides basic information on the seismic vulnerability and strengths of various structural systems and materials, useful to local, national and international public and private organizations and individuals concerned with improving the seismic resistance of a region's housing stock. Initially inaugurated at the 2000 World Conference on Earthquake Engineering in Auckland, New Zealand, this web-based project is now in its fourth year. This paper describes the scope of the encyclopedia and provides the examples of its application.

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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 [1]). 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, over 100 reports describing housing construction practices from 34 countries or territories are included in the database. The distribution of housing reports by continent available in the database 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.

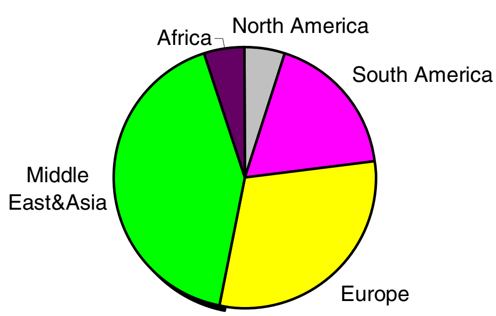

Figure 1. Distribution of housing reports by continent (March 2004)

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. The project has recently made a transition to an Editorial Board that will oversee its development during the next three years. The Editor-in-Chief, six regional editors and four Editors at large are in charge of managing the project, providing an overall direction and developing new initiatives. Each regional Editor coordinates the 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 most powerful features of the web site is the ability to perform a global database search using several search parameters. 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. For example, out of 25 European reports, 19 describe multi-family housing construction, and 6 describe single-family housing. It is also possible to perform searches by the type of load-bearing structure. For example, it is possible to identify all reports describing concrete moment resisting frame structures. There are 21 such reports, from Chile, Colombia, Cyprus, Greece, India, Italy, Kyrgyzstan, Malaysia, Palestinian Territories, Syrian Arab Republic, Taiwan, Turkey, Uzbekistan, Venezuela, Serbia and Montenegro and Romania. Searches on multiple criteria are also possible, for example a search by economic status of inhabitants (e.g. poor) + urban vs. rural construction (e.g. rural) within a country/continent/world.

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, has recently been posted. This tutorial 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 has been developed by a group from the Catholic University of Lima, Peru (Blondet et. al [2]). It contains several downloadable references (papers and manuals) linked to the tutorial 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 intent is that the

tutorials on other construction materials, such as unreinforced masonry (brick/stone), confined masonry, reinforced concrete, and wood construction, will follow a similar template, containing sections on typical performance of this construction material in earthquakes and appropriate seismic strengthening technologies.

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 the engineered construction while the remaining 33 reports are describing nonengineered housing construction practice. Using the 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.

HOUSING REPORTS: INFORMATION CATEGORIES

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 and information on the typical period of practice and regions of the country where such construction has been practiced. See Table 1 for examples from two housing types included in the encyclopedia:

Table 1. Examples of Construction Type Summaries

INDIA *Reinforced concrete frame building with masonry infill walls designed for gravity loads* 	The construction of reinforced concrete buildings with brick masonry infill walls is a very common practice in urban India for the last 25 years. Such construction is found throughout urban areas of the country. Most such construction is designed for gravity loads only in violation of the Indian Standards Code for earthquake-resistant design. These buildings performed very poorly during the Bhuj earthquake of January 2001 in which several thousand such buildings collapsed. The collapse was not limited to the epicentral region. About 75 RCC frame buildings collapsed and several thousand others were damaged in and around Ahmedabad, which is over 250 km from the epicenter, clearly demonstrating the seismic vulnerability of this construction. Jaiswal et al. [3]
CHILE *Reinforced clay/concrete block masonry building* 	This is a rather recent construction practice followed since 1970s, and it has been widely used for dwellings and up to 4-story high apartment buildings. Buildings of this type can be found both in urban and rural areas of Chile. The main load bearing elements are masonry walls reinforced with vertical steel reinforcement bars placed in the hollow cores of clay masonry units (hollow clay tiles) or concrete blocks. Horizontal reinforcement bars are placed in horizontal bed joints. Masonry shear walls are tied together at floor levels by means of reinforced concrete beams, in a regular structural layout. Stiffness distribution both in plan and elevation is uniform. Prior to 1986 there was no seismic design code for this structural type. During the March 3, 1985 Llolleo earthquake, performance of buildings of this type was rather poor, mainly due to construction problems, such as partial grouting in the hollow cores with reinforcement, poor quality of the mortar, and lack of horizontal reinforcement. Following the earthquake, the Chilean Design Code NCh1928 code was published based on the U.S. Uniform Building Code (UBC-1979) and the seismic performance of this construction type reported in previous earthquakes. Since 1993, when the last version of NCh1928.Of93 was published, and more restricted requirements were enforced, the use of this type of construction has been less frequent, in part due to economic reasons. Moroni et. al. [4].

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. 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 2. Structural systems characteristic for concrete housing construction include 7 different types of moment resisting frames (cast in place and precast) and 2 shear wall systems. For example, reinforced concrete frames with masonry infills have been recognized as one of the most vulnerable housing construction practices in Europe, and were affected by the 1999 Athens (Greece) earthquake and the 1999 Turkey earthquakes. This type of construction was also affected by the 1999 Chi Chi (Taiwan) and 2001 Bhuj (India) 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.

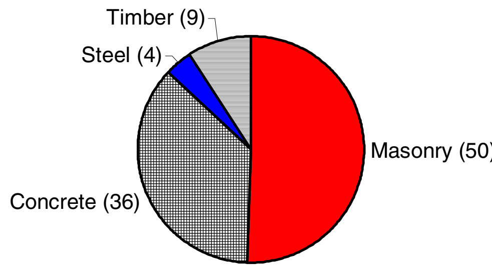

Figure 2 Breakdown of housing reports per building material (number of available reports indicated in the brackets)

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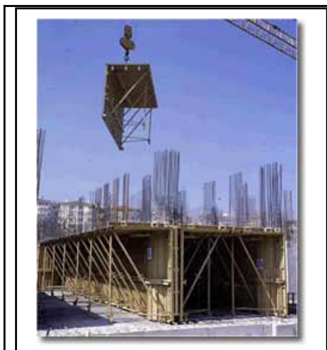
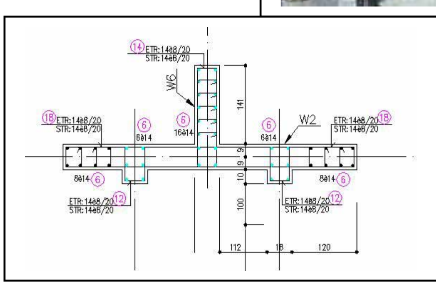
Table 2: Example of Description of Structural System: Tunnel Form Construction in Turkey

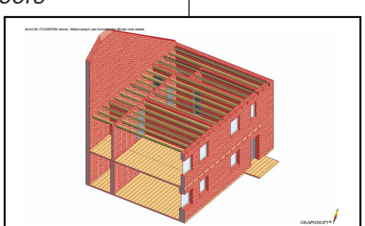
 **A** **B**   **C**	Structural walls provide the lateral-load resistance. The walls and the slab are cast in a single operation using specially designed half-tunnel-steel forms (upside down U shape) that maintains a certain size as shown in Figure A. This cuts down the construction time significantly. The wall and the slab form a monolithic joint. The following construction sequence is implemented. 1) The tunnel forms are first cleaned and coated with form oil. Then they are placed in their positions by using the kicker as the guide (Figure A). 2) The wall reinforcement leads the tunnel formwork. Reinforcement steel and electric conduits are positioned on the tunnel form (Figure B). 3) Walls, slab and kickers are cast. The next morning the formwork is ready to be stripped and carried to the next location by a crane. In accordance with the design, steel blockouts may be installed on the formwork panels to form the plumbing openings. Figures in the report on-line show the elevation and plan of a typical building constructed by this technique. Figure C shows samples of the reinforcement detailing and the structural drawings taken from the blueprints of a typical building. (Gulkan and Yakut [5])

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 2 contains an example of this description

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 3 illustrates the kinds of information provided on seismic features for two different construction types—concrete high rise construction in Canada and brick and timber construction in Romania.

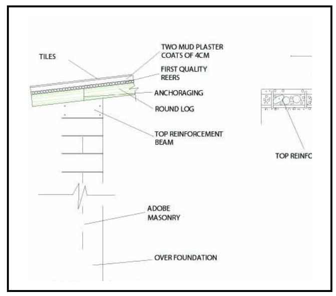
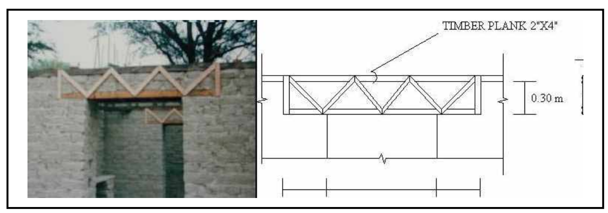
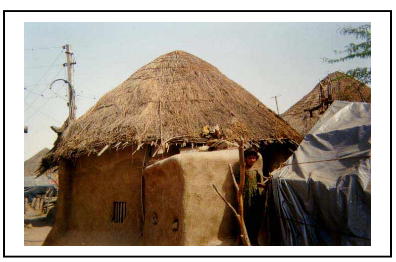
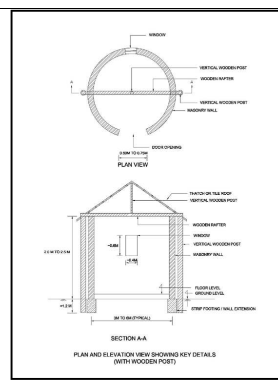
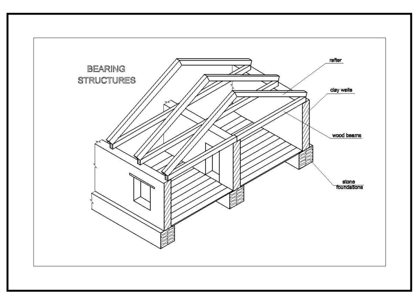
Table 3: Example of Information Provided on Seismic Features

Country and Construction Type	**Structural Element**	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Canada: *Concrete Shear Wall High Rise Buildings*  (Pao and Brzev [9])	Shear wall	Inadequate amount of vertical reinforcement in the wall end zones (boundary elements); - Inadequate lap splices causing non-ductile flexural failure	If properly reinforced (with distributed and end zone reinforcement), ductile seismic behaviour is expected, characterized with the yielding of flexural reinforcement in the plastic hinge zone	Shear failures corresponding to diagonal tension, web crushing, or sliding shear (if shear strength is less than flexural strength); - Shear cracking around wall openings; - Buckling of longitudinal bars in boundary regions of plastic hinge zones (in case of inadequate lateral confinement); - Flexural failure due to insufficient reinforcement lap lengths in the wall end zones (slip of lap splices);
Romania: *Single-family two-story house with brick walls and timber floors*  (Bostenaru and Sandu [10])	Roof and floors	Chimneys insufficiently anchored; - Absence of transverse connections at the perimeter of the floors with timber or metal joists (such connections transfer loads in one direction)	Timber floors ensure uniform load distribution; timber floors with joists each measuring 600 mm ensure the uniform distribution of the in-plane rigidities such that torsional effects are avoided. Timber joists are supported by longitudinal walls (the main direction in the building). Support of the floor with joists which are orthogonal on the longitudinal walls is considered by the authors to have had a certain damping effect during the 1977 earthquake.	Collapse of chimneys; envelope got damaged

Section 5.3 of each report includes the estimate of the seismic vulnerability rating for the housing construction under discussion. The rating is determined according to the EMS scale (EMS [6]). Most of the reports (39 in total) currently available in the database describe the 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, however there are 19 reports describing earthquake-resistant construction (Classes E and F per EMS scale). Examples of earthquake-resistant construction include engineered structures such as reinforced concrete shear wall construction in Chile (Moroni et al. [7]) and tunnel form construction from Turkey (Gulkan and Yakut [5]) to vernacular construction such as traditional timber house (yurt) from Kyrgyzstan (Begaliev and Uranova [8]). It is believed that the users of WHE can benefit both from the information on construction practices that have shown poor performance in past earthquakes as well as on the construction practices that have shown a good earthquake performance.

Table 4: Examples of reports on adobe construction

 **Argentina**: *Traditional adobe house with reinforcement* (Rodriguez et al [11])	
 **Peru**: *Adobe house* (Loaiza et al [12])	
 **India**: *Traditional rural house in Kaachh region (bhonga*) (Choudhary et al [13])	
 **Kyrgyzstan**: *Houses with mud walls and timber roofs (*Uranova and Begaliev [14])	

One of the strong points of the encyclopedia is the ability to compare information across countries and construction types. There are a number of reports on adobe construction, for example, a construction type that has performed notoriously poorly in recent earthquakes, as shown in Table 4. 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. As mentioned above, an important addition to the encyclopedia has been the development of the tutorial on adobe construction, available in both English and Spanish, with a focus on improved building construction practices and available strengthening technologies.

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 unreinforced brick masonry construction in Slovenia.

Table 5: Example of Information from Section 6 in Encyclopedia, Earthquake Damage Patterns

Slovenia—Unreinforced Brick Masonry Apartment Building (Lutman and Tomasevic [15])	

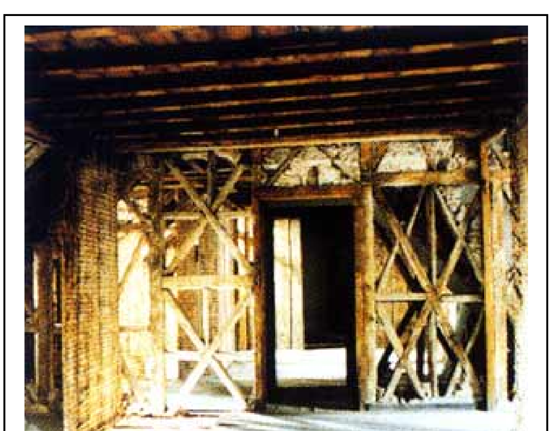
PAST EARTHQUAKES REPORTED TO AFFECT THIS CONSTRUCTION

YEAR	Earthquake Epicenter	Richter Magnitude (M)	Maximum Intensity (Indicate scale e.g. MMI, MSK)
1963	Skopje, Macedonia***	6.0	IX (MSK)
1976	Friuli, Italy*	6.5	IX-X (EMS)
1979	Montenegro, Yugoslavia***	7.2	IX (MCS)
1998	Bovec, Slovenia**	5.5	VII-VIII (EMS)

<u>Description of the earthquake effects</u>: * The epicenters of the main shock on May 6, 1976 (M= 6.5, focal depth 20-30 km) and the strongest aftershock on September 15, 1976 (M=5.9) were in Friuli, Italy, 20.5 km from the border between Italy and Slovenia. In Italy, 965 people died and an enormous damage was caused. In Slovenia, the maximum intensity was VIII EMS. Out of 6,175 damaged buildings, 1,709 had to be demolished and 4,467 were retrofitted.
** The strongest earthquake with the epicenter in Slovenia in the 20th century occurred on April 12, 1998. The epicenter was approx. 6.3 km South-East from the town of Bovec. No building collapses were reported; however, out of 952 inspected buildings, 337 were found to be unsafe, out of which 123 buildings were beyond repair. The majority of damaged buildings were rubble-stone masonry houses. *** This construction was also practiced in Montenegro and Macedonia.

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. [16]) Details of the “Pombalino” building are shown in Figure 3.



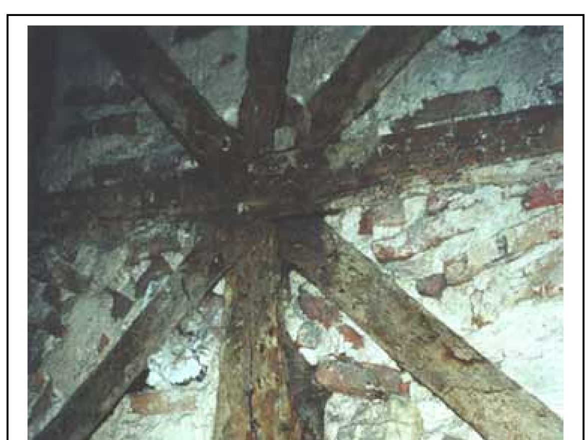


Figure 3. An early form of earthquake-resistant braced frame construction in Portugal (Cardoso et al., [16])

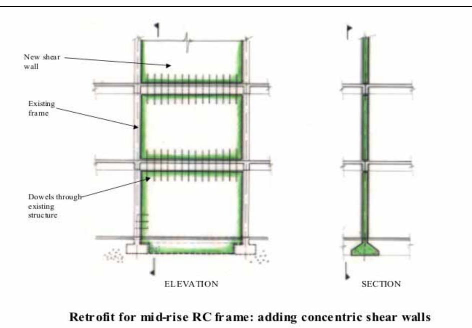
In addition, many reports contain figures illustrating the construction process, as shown in Figure 4.

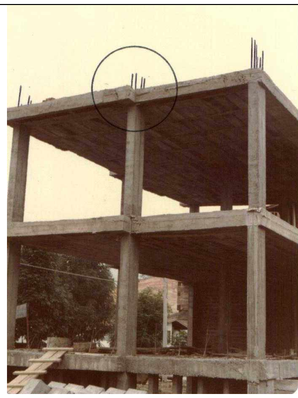
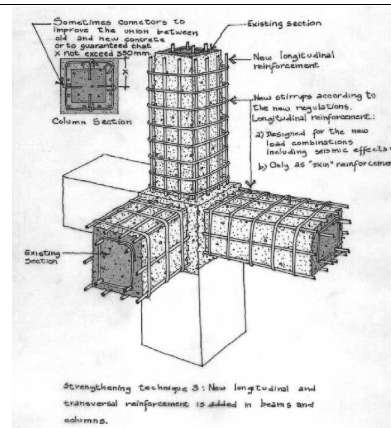
Figure 4: Illustration of Construction Process for Wood Frame Construction in the U.S.A. (Arnold [17])

SEISMIC STRENGTHENING TECHNOLOGIES

This section includes the 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 a range of strengthening techniques are available and are summarized in text and through figures. One of the objectives of the encyclopedia is to enable sharing of 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. Table 6 illustrates some of the examples received for reinforced concrete construction with masonry infill, along with some of the strengthening options presented in each report.

Table 6: Reinforced Concrete Frame Construction and Strengthening Strategies around the World

Turkey (Gulkan et al. [18])		

<table>
<tr><td>Colombia (Mejia, [19])</td><td></td><td>
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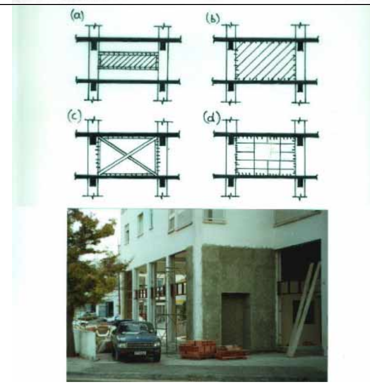
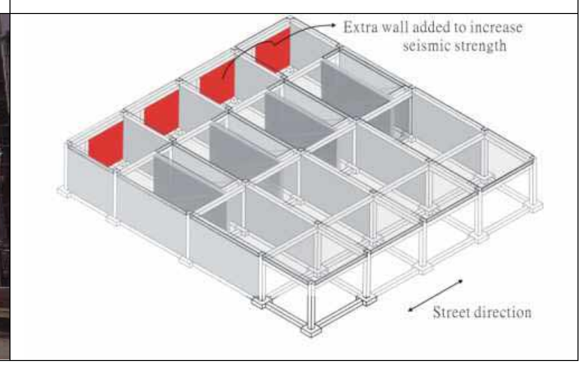
<tr><td>Cyprus (Levtchitch, [20])</td><td></td><td>
</td></tr>
<tr><td colspan="3">Table 6: continued</td></tr>
<tr><td>Taiwan (Yao and Sheu, [21])</td><td></td><td>
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CONCLUSIONS

The WHE web site has received much attention and positive feedback from users around the world. It currently receives between 3,000 and 4,000 unique hits per month, 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 the 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 an easy access to information on various housing practices, and identifying good and bad practices from the seismic performance perspective. The project continues to grow and new participants are welcome. 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.

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