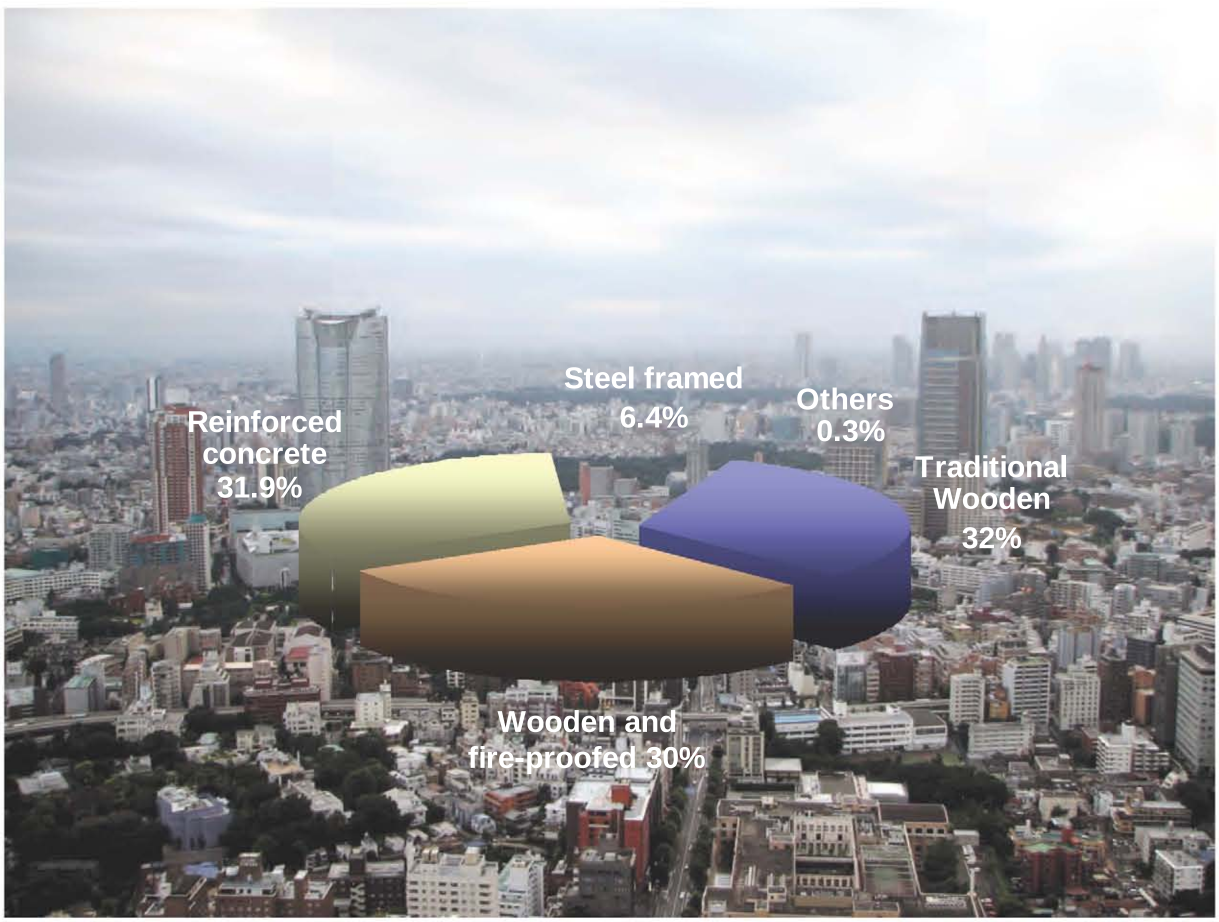
Creating a Global Building Inventory for Earthquake Loss Assessment and Risk Management



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U.S. Geological Survey

Creating a Global Building Inventory for Earthquake Loss Assessment and Risk Management

By Kishor Jaiswal and David J. Wald

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Contents

Contents........ iii
Figures........ v
Tables........ vi
Executive Summary........ 1
Introduction........ 2
Inventory Literature and Data Review........ 4
Inventory Data Sources........ 7
UN Statistical Database on Global Housing (1993)........ 7
UN-HABITAT Database (2007)........ 9
Housing Census Database (Country-Specific)........ 9
World Housing Encyclopedia Database (Country-Specific)........ 10
Data Compiled from Published Literature........ 11
Inventory Development........ 11
Overview........ 11
PAGER Specific Inventory Needs........ 12
Methodology........ 12
Phase I: Database Identification, Preparation, and Confidence Rating........ 13
Data Identification........ 13
Geographic Location and Resolution........ 13
Occupancy Classification........ 13
Construction Type Classification........ 14
Average Occupancy by Construction Type........ 14
Attribute Rating........ 15
Phase II: Data Prioritization, Merging, and Country Assignments........ 15
Selection of Attribute Assignments Using Ratings and Vintage of Data Source........ 15
Phase III: Data Development for Missing Entries and Synthesis........ 16
Missing Entries and Country-Pairing........ 16
PAGER Inventory Matrix Compilation........ 17
Limitations of the Methodology........ 17
Illustration of Inventory Data Compilation for Peru........ 18
United Nations Housing Database........ 18
UN-HABITAT (2007) DHS Database........ 18
Population and Housing Census........ 19
World Housing Encyclopedia (WHE) Reports........ 19
Published Literature of Housing/Building Stock........ 19
Inventory Compilation for Selected Countries........ 20
Australia........ 20
El Salvador........ 20
Indonesia........ 21
Iran........ 21
Italy........ 22
Japan........ 22
Mexico........ 23
Nepal........ 23
New Zealand........ 24
Taiwan........ 24
The Philippines........ 25

Turkey....................25
Application to the Continental United States....................25
Web Delivery of Global Inventory....................26
Implementation Challenges....................27
Processing of Raw Data....................27
Construction Type Mapping....................27
Occupancy by Construction Type....................27
Confidence Rating....................28
Limitations of PAGER Inventory Database....................28
Housing Units and Building/Structure Type Inventory....................28
Wall Material and Structure Type....................28
Vintage of Database....................29
Resolution of Inventory Distribution....................29
Scope of Inventory Updating....................29
Summary....................30
Conclusions....................31
Acknowledgments....................32
References Cited....................33
Glossary....................41
Appendix I....................42
Appendix II....................45
Appendix III....................47
Appendix IV....................52
Appendix V....................57
Appendix VI....................64
Appendix VII....................69

Figures

Figure 1. Histogram showing housing units by construction material for Hungary 87
Figure 2. Schematic overview flowchart of the PAGER inventory development methodology 88
Figure 3. Schematic flowchart of the PAGER inventory development methodology (Phase I – Population of databases and ratings) 89
Figure 4. Schematic flowchart of the PAGER Inventory Development Methodology (Phase II - Merging of Databases) 90
Figure 5. Map showing geographic coverage by country of the building inventory data from different sources aggregated in Phase II 91
Figure 6. Map showing the housing stock distribution pattern of Iran, identified as a possible representative building stock distribution for Afghanistan (where data is not available) based on recent vintage and rating of Iran over data from Pakistan........... 92
Figure 7. Map showing identification of most representative neighbor for Ecuador from all neighboring countries 93
Figure 8. Map showing the building stock distribution in Armenia, used as a proxy for Azerbaijan based on data vintage 94
Figure 9. Schematic flowchart of the PAGER inventory development methodology (Phase III – Filling the missing elements) 95
Figure 10. Photograph showing typical rural house in Bangladesh made of straw, mud, and timber frame 96
Figure 11. Photograph showing general housing stock in Thailand (Bangkok) obtained from general Internet search 97
Figure 12. Bar chart showing housing stock distribution for Peru (United Nations, 1993) 98
Figure 13. Photograph showing typical residential building stock in Peru constructed using brick masonry construction 99
Figure 14. Pie chart showing distribution of housing stock in urban areas of Peru obtained from WHE-PAGER expert survey 100
Figure 15. Pie chart showing distribution of housing stock in urban and rural areas of Iran obtained from housing census data (Iran Statistical Year Book, 2005)............... 101
Figure 16. Photograph showing typical multistoried reinforced concrete apartment buildings with masonry infill walls in Ankara, Turkey 102
Figure 17. Map showing global coverage of PAGER building inventory database with data compiled from various sources 103

Tables

Table 1. Tabulation of the types of data sources, their parameters, assigned quality ratings, and their coverage 70
Table 2. Housing units by construction material of external walls in the year 2004 for Tanzania from the UN (2007) database 72
Table 3. List of countries, source of contact, and web links for countries with housing census data........ 72
Table 4. (a) Census data compiled by the National Statistical Office of the Government of the Philippines for housing inventory by construction material, (b) Housing Census data showing distribution of housing units by construction material (wall and roof construction) for Pakistan........ 73
Table 5. List of countries with inventory data from published country-specific resources, articles, and reports 74
Table 6. Residential construction type distribution for several Middle-Eastern countries, from Petrovski (1983)........ 75
Table 7. Housing stock distribution based on UN-HABITAT (2007) compiled for Peru 76
Table 8. Housing stock distribution based on the 2000 Census of Population and Housing compiled for Australia 76
Table 9. Housing stock distribution based on the 1990 Census of Population and Housing compiled for El Salvador 77
Table 10. Housing stock distribution based on the Census of Population and Housing (2001) compiled for Indonesia........ 77
Table 11. Housing stock distribution based on Ghafory-Ashtiany and Mousavi (2005) for the city of Bam, Iran........ 78
Table 12. Distribution of residential building stock in Italy 78
Table 13. Distribution of residential building stock in Japan 79
Table 14. Distribution of residential building stock in Mexico........ 79
Table 15. Distribution of residential building stock in Nepal........ 80
Table 16. Distribution of residential building stock in New Zealand 80
Table 17. Distribution of residential building stock in Taiwan........ 81
Table 18. Distribution of residential building stock in Philippines........ 81
Table 19. Distribution of residential building stock in Turkey 82
Table 20. Distribution of California building stock as obtained from the HAZUS (FEMA, 2006) inventory database 83
Table 21. List of countries that provide inventory data obtained during WHE-PAGER survey and the name of the experts........ 85
Table 22. WHE-PAGER survey response for Japan, contributed by Dr. Charles Scawthorn from Kyoto University, Japan 86

Creating a Global Building Inventory for Earthquake Loss Assessment and Risk Management

By Kishor Jaiswal[1] and David J. Wald[2]

Executive Summary

Earthquakes have claimed approximately 8 million lives over the last 2,000 years (Dunbar, Lockridge and others, 1992) and fatality rates are likely to continue to rise with increased population and urbanizations of global settlements especially in developing countries. More than 75% of earthquake-related human casualties are caused by the collapse of buildings or structures (Coburn and Spence, 2002). It is disheartening to note that large fractions of the world's population still reside in informal, poorly-constructed & non-engineered dwellings which have high susceptibility to collapse during earthquakes. Moreover, with increasing urbanization half of world's population now lives in urban areas (United Nations, 2001), and half of these urban centers are located in earthquake-prone regions (Bilham, 2004). The poor performance of most building stocks during earthquakes remains a primary societal concern. However, despite this dark history and bleaker future trends, there are no comprehensive global building inventories of sufficient quality and coverage to adequately address and characterize future earthquake losses. Such an inventory is vital both for earthquake loss mitigation and for earthquake disaster response purposes. While the latter purpose is the motivation of this work, we hope that the global building inventory database described herein will find widespread use for other mitigation efforts as well.

For a real-time earthquake impact alert system, such as U.S. Geological Survey's (USGS) Prompt Assessment of Global Earthquakes for Response (PAGER), (Wald, Earle and others, 2006), we seek to rapidly evaluate potential casualties associated with earthquake ground shaking for any region of the world. The casualty estimation is based primarily on (1) rapid estimation of the ground shaking hazard, (2) aggregating the population exposure within different building types, and (3) estimating the casualties from the collapse of vulnerable buildings. Thus, the contribution of building stock, its relative vulnerability, and distribution are vital components for determining the extent of casualties during an earthquake.

It is evident from large deadly historical earthquakes that the distribution of vulnerable structures and their occupancy level during an earthquake control the severity of human losses. For example, though the number of strong earthquakes in California is comparable to that of Iran, the total earthquake-related casualties in California during the last 100 years are dramatically lower than the casualties from several individual Iranian earthquakes. The relatively low casualties count in California is attributed mainly to the fact that more than 90 percent of the building stock in California is made of wood and is designed to withstand moderate to large earthquakes (Kircher,

[1] U.S. Geological Survey, National Earthquake Information Center, 1711 Illinois St. Golden, CO 80401 (contracted through Synergetics Incorporated - *http://www.synergetics.com*).
[2] U.S. Geological Survey, National Earthquake Information Center, 1711 Illinois St. Golden, CO 80401.

Seligson and others, 2006). In contrast, the 80 percent adobe and or non-engineered masonry building stock with poor lateral load resisting systems in Iran succumbs even for moderate levels of ground shaking. Consequently, the heavy death toll for the 2003 Bam, Iran earthquake, which claimed 31,828 lives (Ghafory-Ashtiany and Mousavi, 2005), is directly attributable to such poorly resistant construction, and future events will produce comparable losses unless practices change. Similarly, multistory, precast-concrete framed buildings caused heavy casualties in the 1988 Spitak, Armenia earthquake (Bertero, 1989); weaker masonry and reinforced-concrete framed construction designed for gravity loads with soft first stories dominated losses in the Bhuj, India earthquake of 2001 (Madabhushi and Haigh, 2005); and adobe and weak masonry dwellings in Peru controlled the death toll in the Peru earthquake of 2007 (Taucer, J. and others, 2007). Spence (2007) after conducting a brief survey of most lethal earthquakes since 1960 found that building collapses remains a major cause of earthquake mortality and unreinforced masonry buildings are one of the most vulnerable building stock throughout the world. Hence, it becomes clear that mapping out the extreme variations of the vulnerabilities in global building inventories is essential for both long-term earthquake loss mitigation and for rapidly identifying disasters. Unfortunately, information about the global building stock and its vulnerability is very limited and most often nonexistent. Building inventory and vulnerability data are publicly available only for handful of countries or regions around the globe.

This report describes the procedure that has been adopted as a first pass at the development of a global building inventory database. The inventory development consists of estimates of the fractions of building types observed in each country, their functional use, and average day and night occupancy. Various data sources exist that provide building-specific information at a local or regional level with varying degrees of confidence; however, few data sources have been found to be relevant, consistent, and useful to our needs on a global scale. The inventory development methodology presented in this report not only compiles data from various sources but also allows us to rate and select the best source based on its vintage and quality. The building-specific inventory distribution developed is necessary for the casualty estimation methodology used for the U.S. Geological Survey's Prompt Assessment of Global Earthquakes for Response (PAGER) system.

The database developed during this investigation has been made available as an electronic supplement (Appendix VII) of this report. The database contains four tables, each reflecting a combination of urban or rural, residential or non-residential category. The fraction of building types or dwellings and their occupancy characteristics have been collated for each country to represent a country-specific distribution (represented by a row in each of the four table specific to a country and is also representative of population exposure) by PAGER structure types. As more data become available, we expect that the existing online inventory database will get replaced in parts with better quality data. The inventory database developed herein exists in the public domain, subject to peer review, scrutiny, and open enhancement. The database is available in most common accessible and readable format (Microsoft Excel spreadsheet) for the worldwide user community. Having the electronic supplement of this database will not only help users to access it online but will also allow the possibility of enhancing the quality of data through an open review and development process.

Introduction

The U.S. Geological Survey's (USGS) PAGER system (Wald and others, 2006) produces ShakeMaps shortly after all global earthquakes (M > 5.5); the system then produces alerts indicating the population exposed to each unit intensity level. PAGER is now being enhanced to allow rapid loss-estimation capabilities. Standard engineering approaches for loss estimation (with explicit modeling of damage to the built environment) require knowledge of affected building stock, its spatial, structural, and occupancy characteristics, yet such data are few and far between.

Some of the existing data sources for inventory database development include the EMERCOM database developed by Russian Federation (Shakhramanian, Larionov and others, 2000), housing data compiled by the statistical agency of United Nations (United Nations, 1993), data on durable housing compiled by UN-HABITAT (2007) based on the Demographic and Health Survey (DHS), data compiled by Population and Housing Censuses of individual countries (United Nations, 2005), and the World Housing Encyclopedia (WHE) database developed by EERI (EERI, 2007). There also exist country-specific inventory databases compiled by various reinsurance agencies such as Munich[3] and Swiss Re[4], and catastrophe modelers such as RMS[5] and EQECAT[6]. In addition to these potential sources, inventory data can also be extracted from individual country- or region-specific research studies. Among these, the research documents that are compiled after any large earthquake or developed for regional or national loss estimation studies are often quite useful. Alternatively, the inventory databases compiled by insurance and reinsurance industries have been developed with varying degrees of relevance (either with limited coverage in terms of geographic location or applicable for specific, often limited to insured, facility types) and for varying applications (mostly financial impact and loss estimations for insured exposure). In addition, most of these developments are not easily accessible or not available for use due to their proprietary nature. Similarly, human settlement and inventory databases, such as EMERCOM, are not publicly accessible either for verification or for use in other approaches of global earthquake risk mitigation.

Reliable inventory information in the form of building stock, their structural systems, and occupancy characteristics forms the requisite input for damage and loss estimation studies. Limitations in inventory data generally have significant impact on other aspects of earthquake loss and risk estimation studies (ATC., 1985; Coburn and Spence, 1992; Shakhramanian, Larionov and others, 2000; Bommer, Spence and others, 2002; FEMA, 2006). The present investigation is focused on creating an open, peer-reviewed database of the global building stock distribution that contains the critical spatial, structural, and occupancy-related information necessary for casualty estimation models for the PAGER project. As the development of this database is based on a systematic approach across all regions and countries, it is expected that additional modification and improvement of the existing data in this database could be most easily carried out and verified in an open, global data development environment.

Several casualty estimation studies in the past have noted the critical importance of knowledge of regional building inventories for rapid earthquake impact assessment (Coburn, Pomonis and others, 1989; Shiono, Krimgold and others, 1991a; Stojanovski and Dong, 1994); and many have suggested the need of development of either a regional database or a database for earthquake-prone areas of the world (Shiono, Krimgold and others, 1991b). The motivation for deriving a global residential building inventory database is from a practical need to characterize the building stock distribution and estimate the vulnerability of building stock to earthquake shaking. This would help in estimation of likely fatalities as part of an effort to rapidly predict ground

[3] Munich Reinsurance Agency (http://www.munichre.com)
[4] Swiss Reinsurance Agency (http://www.swissre.com)
[5] Risk Management Solutions (http://www.rms.com)
[6] EQECAT (http://www.eqecat.com)

shaking and earthquake impact globally. This is one key objective for the Prompt Assessment of Global Earthquakes for Response (PAGER) program of the USGS's National Earthquake Information Center (Wald, Earle and others, 2006). Among the factors that contribute to heavy casualties from significant earthquakes, vulnerable building stocks remain the main cause of concern (Coburn and Spence, 2002). Consequently, we require at least a first-order approximation of building inventory distribution in all earthquake-affected regions in order to estimate the likely number of building collapses that may take place during an earthquake. Beyond this specific application, we also expect that such an inventory database may also encourage researchers or stakeholders from different countries to develop more refined regionally specific inventory databases to augment our efforts. Such developments or verification will potentially help the future updates to the PAGER inventory database and improve casualty estimation models in general.

In our inventory database development, we compile the building inventory information in a three-phased approach. In the first phase, we identify various databases that provide mainly residential housing building stock distributions for individual countries and then map the raw description about construction material or building types in terms of PAGER construction types (Appendix I). At this point, we also assess and rate their quality based on the data source and the rigor of the source's original compilation. In the second phase, after preparing the individual databases, we then merge them together and pick the highest rated (quality) information to produce a single database without mixing or modifying individual input. In the third and last phase, we identify and develop housing attributes for missing elements (that is structural inventory distribution or occupancy) of countries with no or poor quality data by identifying the most appropriate neighboring or analog country for those missing data. This selection is based on rating and vintage of all the neighboring countries' data in conjunction with subjective judgment for assignments of missing attributes from selected neighbors. While performing the country-pairing assignments, we only use the distribution of housing stock as a possible representation of the housing stock distribution for a missing country and not the actual number of housing types or units of the neighboring country. Finally, we develop a single inventory matrix for global housing stock by country, while allowing for the possibility of easy updates in the future for higher quality data for individual countries as well as finer resolution subdivisions within a country (for example, inventory by city or administrative units within a country). The global building inventory developed in this report has several limitations, and we are currently considering various approaches that may improve these deficiencies, including input from the WHE country-specific contributions (Porter, Greene and others, 2008).

Inventory Literature and Data Review

Various loss estimation methodologies at both the regional and national level developed in the past rely on inventory information with a primary focus on accurate assessment of the economic impact of an earthquake. The inventory methodology developed by the Applied Technology Council's ATC-13 project, and incorporated in the database development in Federal Emergency Management Agency's (FEMA) loss assessment software HAZUS (FEMA, 2006), uses a consensus-based approach. The ATC-13 approach, which mainly focuses on the existing facilities in California, classifies the building stock both in terms of structural class (36 types based on the structural system) and occupancy class (78 types based on the facility's use) (ATC., 1985). The Level 1 procedure in the ATC-13 approach consists of identifying a unique combination of postal ZIP code, Social Function Classification, and Earthquake Engineering Facility Classification and then completing all or most of the elements of their inventory matrix. Level 2 and 3 procedures consist of completing the missing elements of the inventory matrix for which data are not available from existing facility databases. The classification scheme proposed in the report has been developed in collaboration with engineering professionals from California. Various facility-specific, pre-compiled databases have been used in the inventory development. These are Census of Population and Housing, tax assessors' records used for development of residential building inventory, and the Dun & Bradstreet database at the census block level aggregated by the Standard Industrial Classification (SIC) used for nonresidential environment, high-rise building database, as well as Government and critical facility databases. The inventory developed for HAZUS software is applicable for the U.S. and is based on a similar principle of building classification, except that it uses 28 occupancy classes (FEMA, 2006). The HAZUS methodology uses the most recent census to estimate square footage for each occupancy class and census tract in the country. It also uses characteristics relationships (developed in part via conducting local workshops), between model building types and occupancy classes to estimate the fraction of square footage for each of the model building types. Thus, both the ATC-13 and the HAZUS building inventories require a relationship between model building type and occupancy class on the basis of floor area. Development of such a relationship requires a high level of expertise and knowledge about the variation of building structure types across a broad range of occupancies throughout the region. Estimation of square footage distribution using Occupancy vs. Structure type distribution sought from experts does have some serious limitations as shown from a pilot study of inventory development carried out for the Manhattan area in New York by Mylonakis and others (2000). The inventory methodology used in ATC-13 and HAZUS development was peer reviewed and has been designed to take advantage of data available from various sources; it will also accommodate various future modifications that may be necessary in augmenting the HAZUS modeling needs. However, the development of model building type or occupancy characteristics from square footage data in ATC-13 and HAZUS relies on expert opinion and thus requires validation. Similarly, it is extremely difficult to gather such expertise at a global scale for each country or earthquake prone region.

The earthquake consequence forecasting methodology developed by EXTREMUM developers (Shakhramanian, Larionov and others, 2000) uses inventory data extracted from population and building information in 89 regions with 2800 administrative units of the Russian Federation. The authors have indicated the distribution of different building types within a town or district and the distribution of people in the different building types during the day and night; however, the exact procedure of inventory development has not been described in detail. It is also unclear as to whether the building type distribution and population exposure data have been field validated. A version of EXTREMUM called QUAKELOSS and created by researchers of the Extreme Situations Research Center in Moscow is currently being used by World Agency of Planetary Monitoring and Earthquake Risk Reduction (WAPMERR) (*http://www.wapmerr.org/origin.html*).

A questionnaire-based procedure was used by Petrovski (1983) to estimate the fraction of building types in several Middle Eastern countries and to understand the associated vulnerability characteristics in the region, for the purpose of planning for future needs. The information gathered through questionnaires, however, suggested that only 8 out of 10 countries were able to contribute to the data development on building distributions, and practically no corresponding data were available on the type of engineered structures or other facility types.

A scenario-based building loss and casualty estimation model developed by Bogazici University (Erdik and Aydinoglu, 2002; Erdik, Aydinoglu and others, 2003; Erdik and Fahjan, 2006) for estimating a worst case scenario of earthquake on main Marmara fault near Istanbul, Turkey, utilizes building inventory and population information from the State Statistical Institute.

The system uses building stock data classified primarily based on structural systems and the number of stories and age of construction, both determined on a fine spatial grid (approx. of 400 m x 600 m) covering 28 districts. The day and time population was estimated using the Istanbul Transportation Master Plan of the Istanbul Metropolitan Municipality.

Other loss estimation models such as a GIS-based computer program, "Early Post-Earthquake Damage Assessment Tool" (EPEDAT), designed to produce regional damage and casualty estimates for southern California, use inventory data from county assessors' records for buildings, and housing census and employment data for exposed populations (Eguchi, Goltz and others, 1997). EPEDAT inventory data include building location, age, use, height, and structural type of buildings developed from data provided by county assessors for five counties of southern California. However, the exact procedure used to determine day and night time population distribution, building type classification, and their occupancy characteristics for six counties has not been discussed in detail by the authors (and remains proprietary in nature). Recently, Geoscience Australia has launched a two-phase project for development of national building exposure database (Nadimpalli, Cornish and others, 2002). The first phase consists of residential building inventory data development for Australia using data sources including a nationally geo-coded address file developed by the Public Sector Mapping Agency (PSMA) along with building-specific data (for example, address, number of occupants, type of dwelling and its valuation) from the Australian Bureau of Statistics (ABS) and the Australian Housing Survey (AHS). The second phase consists of development of a building inventory database for commercial and industrial buildings which is still in the design phase. It is worth noting that inventory development at a country or even regional level requires substantial efforts both in terms of identification and data compilation. In many countries, the base inventory data necessary for completion of a loss-database do not exist, are not available, or are in inaccessible forms.

Recent developments in inventory development at regional levels for earthquake loss estimation include the ongoing LESSLOSS project, which was launched by European Centers of Excellence in earthquake and geotechnical engineering, focusing on risk mitigation for earthquakes and landslides in European countries. The LESSLOSS project addresses natural disasters, risk and impact assessment, natural hazard monitoring, mapping and management strategies, improved disaster preparedness and mitigation, development of advanced methods for risk assessment, methods of appraising environmental quality and relevant pre-normative research (*www.lessloss.org*).

Another ongoing European project, Network of Research Infrastructures for European Seismology (NERIES), also focuses on development of a new generation of hazard and risk assessment tools designed to improve monitoring and understanding of the earthquake process. NERIES will combine networking, transnational access and joint research activities to promote improved access to distributed databases, common protocols, standardized procedures and strategies for long-term archiving and distribution of seismological data. The project will mainly strengthen the role of European seismology in global seismic monitoring and hazard mitigation (*http://neries.knmi.nl*). One of the products by NERIES which is under development is a loss estimation tool similar to HAZUS.

In order to develop an inventory of building types, several key data sources have been identified that provide information in various forms, as shown in table 1. Each of these sources has been studied in detail for the information content and its usability in the PAGER framework. The World Housing Encyclopedia (WHE) database covers 110 housing types (as of Jan. 10, 2007) contributed by 180 volunteer engineers and architects from various countries and regions (*http://www.world-housing.net/*). Each of the forms covers information pertaining to structural, occupancy, and socio-economic characteristics of a particular building type reported by WHE volunteers. The information available in WHE forms is peer reviewed by international experts of the respective field and region.

The United Nations and its various agencies (such as UN-HABITAT[7], UN Dept of Statistics[8], Urban-Info database[9]) have been compiling demographic or housing data such as population, number of households and housing types, and its construction material for decades. Housing data compiled by UN agencies not only assist local governments in reviewing housing conditions in their own countries but also offer users a comprehensive overview of housing and its statistics worldwide. The main sources of UN housing data are official census publications of individual countries dealing with housing characteristics of the population. According to UN Statistics Department, during the 1990 round of census, about 197 countries have collected statistical data on housing through a census or through a survey as a part of the census. However, many of these countries did not compile data related to distribution of housing types by construction material (the materials used for construction of roof, wall, or floors of a dwelling). The UN (1993) housing data publication provides data on construction material used for wall construction for 40 countries (most of the countries in the African continent). UN-HABITAT (2007) database on durable housing provides information on fraction of housing types by material used for construction of wall/roof/floor based on Demographic and Housing Survey (DHS). Despite the availability of data on the fraction of dwellings with floor or roof construction material for many countries, the data could not be used directly to deduce the construction types. In general, the construction material used for building a structural system (mainly walls in case of a gravity-load-bearing system) that supports roof and floor elements of a dwelling is useful for mapping the construction types. Additional information is necessary in order to estimate a structural system from roof or floor material dataset which varies from country to country and is not easily available. Similarly, most of the census surveys or UN sponsored surveys, as just discussed, also provide information in terms of housing types (conventional, temporary or marginal dwellings) as mentioned in subsequent sections. However, additional knowledge about distribution of each of housing types into various construction types is generally not provided and thus was not available for PAGER database development.

Inventory Data Sources

We have performed a short but intensive search to understand what data exist internationally about the nature of building stock and the way it has been developed and also sources of information from which the data may be gathered. This section presents a short summary of various databases that have been identified to be potentially used for PAGER inventory development.

UN Statistical Database on Global Housing (1993)

One of the most important sources of data on global residential housing stock has been prepared by the United Nations Statistical Division (UNSD), Department of Economic and Social Information and Policy analysis of the United Nations Secretariat (United Nations, 1993). The purpose of the database is mainly to assist the governments of respective countries in reviewing

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[7] United Nations HABITAT project (http://www.unchs.org)
[8] United Nations Department of Statistics (http://unstats.un.org/unsd/demographic/sources/census/default.aspx)
[9] United Nations Urban Info Data Center (http://www.devinfo.info/urbaninfo)

housing conditions. This database also provides a comprehensive and graphical overview of housing in the world and guides users to sources of housing statistics worldwide. According to UN (1993), the main source used for compilation of the housing data was the official census publications dealing with housing characteristics of the population. However, when data were not published in the census series, UN compilations were based on other sources such as statistical yearbooks of the country, which also provide housing information.

The "Compendium of Human Settlements Statistics 2001" covers 243 countries and includes "housing" as one of its five main sections (United Nations, 2001). The UNSD also lists the dates for recent country-level housing and population census and gives Web links to some of these data. Some countries have carried out population surveys but have not included housing surveys in their census. The UN (1993) publication on housing-type data covers 136 countries; however, PAGER's structure type distribution database compilation was not based on housing type. This is mainly because housing type description does not represent the structural system; rather, it only provides information about dwelling type, for example, temporary, conventional, marginal or basic dwellings. Such description could not be utilized immediately into PAGER inventory development unless further classification of each type of dwelling by its construction material or structural system becomes available. Figure 1 illustrates a broad description of inventory by external wall material of occupied dwellings in Hungary. It is obtained from 2 percent of the representative sample study conducted by Hungarian Central Statistical Office and later compiled by United Nations publication (United Nations, 1993). The description of construction material such as adobe, wood, or concrete, provides useful information about likely construction type.

A housing unit is a separate and independent place of abode intended for habitation by one household, or one not intended for habitation but occupied as living quarters by a household at the time of census or other inquiry. Housing units consist of both conventional and unconventional dwellings. About 44 countries had data for construction material of external walls in the UN (1993) publication, which refers to the construction material of the outer walls of the building in which the living quarters are located. If the outer walls are constructed of one or more materials, the predominant material is usually indicated. This database has several limitations, as follows:

- It does not represent the complete structure type distribution (residential versus nonresidential building stock).
- It represents housing units (in which several housing units could be part of a single building) by construction material rather than by the fraction of buildings by construction material.
- For some countries, it utilizes colloquial names for the construction material instead of uniform nomenclature across the countries (for example, "quirintin" in some African countries which refers to woven branches and straw used as construction material). This makes the mapping exercise laborious in terms of searching and mapping each and every individual terminology of the local construction material with standard or more common nomenclature of construction material.
- It does not provide information about structural system required to assess the performance of building during earthquake ground shaking. Hence it was necessary to make certain assumptions while mapping the construction material types with common structure types. This was very time consuming and often required higher order assumptions to convert the raw database into more uniform PAGER structure type distributions using a predefined mapping scheme.

- The development of the database is not based on uniform procedures, and no engineering expertise was sought to demarcate common construction. Similarly, no engineering surveys were carried out either to develop the fraction of housing type data or to verify existing inputs available from individual countries.
- The database development is not intended to be used for carrying out engineering loss estimation studies.

Despite all the limitations, this database provided the most basic input about construction types for almost 40 countries and hence has been utilized in the PAGER inventory development even though we assigned them a “Low” rating level. The need behind using UN (1993) publication was to consider all available databases of variable quality in the absence of any particular reliable inventory data source at global coverage. Also, the engineering survey-based inventory information was available for only handful of regions or countries in the world. We seek to utilize all available data sources including the UN (1993) publication and to develop a single database with a uniform mapping scheme which also could potentially be useful for future updation.

UN-HABITAT Database (2007)

The United Nations Human Settlements Program, UN-HABITAT, is the United Nations agency for human settlements. It is mandated by the UN General Assembly to promote socially and environmentally sustainable towns and cities with the goal of providing adequate shelter for all (*http://www.unhabitat.org*). We obtained data on durable housing (mainly giving distribution of housing types in terms of construction material used for wall, roof or floors) directly from the office of Human settlement program of United Nations through written communication. Data are available for more than 60 countries and procured through the Demographic and Health Survey (DHS) conducted in each country (UN-HABITAT, 2007). Only 22 countries have information on the distribution of housing units. Table 2 shows an example dataset for Tanzania compiled by UN-HABITAT. The dataset is based on descriptions of the predominant material that has been used for the construction of external walls in Tanzania. Data on floor and roof construction materials could not be utilized for defining the construction types because the basic structural system is generally characterized by the building elements (such as load-bearing walls, beam-columns, moment frames, or shear walls) that resist the lateral loading during earthquakes.

As the database compilation for durable housing in the (UN-HABITAT, 2007) database was similar to the procedure adopted for (United Nations, 1993) database compilation, the inherent issues related to housing units versus building data; lack of uniformity in nomenclature of construction material and lack of engineering expertise in carrying out surveys limit the applicability of this database. We assigned “Low” quality to this database and thus it forms the basic layer of information about housing in a particular country where no other source of information is available. Though both the (United Nations, 1993) and (UN-HABITAT, 2007) database have the same quality ratings, most of the data in (UN-HABITAT, 2007) database was obtained more recently and hence is considered preferable to the (United Nations, 1993) data for any country where both databases are available.

Housing Census Database (Country-Specific)

In the 2000 round (the 1995-2004 census decade), about 173 countries conducted housing censuses. Still, many countries in the world either have not planned for conducting housing census or have not shared the information with United Nations Statistics Division. Among the 131 countries for which the housing census data were available to the United Nations office, only 73 countries have data related to the construction material of the outer walls of buildings. For many countries, the data seem to be available on the Web site of the respective statistical office. In the present exercise, we compiled housing census data for eight countries that have made their data available online. Table 3 provides a list of countries and the associated Web addresses from which the data have been downloaded and compiled for PAGER inventory development.

The housing census compilations were not carried out by engineering professionals and hence the data provide only a limited contribution for engineering characterization of construction types. Following common practice, we deduced the information about the housing types from the use of the material for construction of the roof, floors, and external walls. Almost all housing census uses this indicator to compile information about state and quality of housing in respective countries. If the walls were constructed of more than one type of material, the predominant type of material was reported. Due to colloquial terminology for defining construction materials, it was necessary to perform general Web research to understand the description of each of such variants and map them with standard nomenclature. Often we referred to pictures of general housing types available online to understand more about these descriptions and then used engineering judgment to map them to appropriate PAGER structure type categories. For some terms, there was some ambiguity in interpretation due to the lack of adequate information about typical construction; however, this uncertainty could be reduced by involving local engineering professionals. Future versions of this open database could incorporate such critical inputs to modify and reestimate the fraction of those construction types in respective countries.

Though the housing census surveys are not intended for database development for earthquake loss estimation studies, housing census data do represent the characteristics of the housing of the entire population and entire geographic extent of the country. The level of details and procedures involved in compiling such information is quite exhaustive, and hence we have assigned "Medium" quality to data derived from housing census. Table 4a shows typical housing characteristics data obtained by the National Statistical office of the Philippines. In the present approach, we are interested in estimating the distribution of housing units by construction material of the external wall, and data available for Philippines provide direct estimation of these fractions. We mapped the description of wall materials to the standard PAGER structure types using Appendix IV. For example wood as well as bamboo / sawali / cogon / nipa descriptions in Philippines have been mapped into the general wood construction (W) category which forms 45 percent of total housing stock in Philippines. Another example includes housing census data available for Pakistan as shown in table 4b. A similar procedure was used to map and estimate the fraction of each mapped PAGER structure types in Pakistan.

World Housing Encyclopedia Database (Country-Specific)

The World Housing Encyclopedia (WHE) is a joint initiative of Earthquake Engineering Research Institute (EERI) and International Association for Earthquake Engineering (IAEE) to develop an interactive Web-based encyclopedia of housing construction types in seismically active areas of the world (EERI, 2007). The database contains a comprehensive global categorization of characteristic housing construction types across the world. The housing type report includes all relevant aspects of housing construction, such as socio-economic issues, architectural features, structural system, seismic deficiencies and earthquake-resistant features, performance in past earthquakes, available strengthening technologies, building materials used, construction process employed, and insurance conditions. In addition to the structure-specific information, several illustrative photos, drawings, sketches are also included in the report. However, despite such elaborate information, the WHE database does not contain inventory and vulnerability-specific information for all the structure types, which are of importance to PAGER development. Subsequent sections will describe the details of housing type database compilation along with occupancy and inventory information extraction from each WHE housing type form available in the WHE database.

Data Compiled from Published Literature

Published literature about earthquake vulnerability or loss estimation methodologies provides important input for assessing the inventory characteristics of specific countries. Several research studies in the past have dealt with challenges of regional inventory compilations or country-specific building vulnerability characterization (for example, ATC-13, HAZUS, KOERIloss). In addition to these sources, other region-specific studies such as Petrovski (1983) and EQRM development (Sinadinovski, Edwards and others, 2003; Robinson, Dhu and others, 2006) provides country-specific building characteristics and distributions. Although, some of the loss modeling applications is available online, the inventory specific information is generally not available for public use. In the present investigation, we utilized publicly available information for building inventory as an additional data source to PAGER inventory development. As most of the data in published literature on inventory have been peer reviewed by engineering professionals, we assigned a “High” quality to them. Table 5 provides a list of countries and the associated data source (published article or loss assessment tool) and it’s vintage. At present, the list covers only limited countries; however, we expect that it will grow as we collect more data from published literature for individual countries.

As the data from most of the loss estimation studies have already been mapped using standard model building types classification schemes (for example, HAZUS model building types for the U.S. and California), it was relatively easy to map them into equivalent PAGER structure types using engineering judgment. Table 6 provides a standing mapping scheme that has been adopted for structure type mapping for Middle Eastern countries based on the Petrovski (1983) inventory distribution for urban areas. The construction type mapping from HAZUS model building types to PAGER structure types is discussed in a subsequent section.

Inventory Development

Overview

The inventory data needs of PAGER have a much wider geographic scope than required in previous studies. Hence, a number of techniques and processes need to be considered before a consensus is made to satisfy regional needs and data constraints. For example, in order to estimate the fraction of building types, it was necessary to classify the worldwide building types broadly based on predominant construction material used for the construction of the walls and their structural systems. The choice of limited categories for building types was mainly due to lack of sufficient information about structural systems, and the limited scientific information about performance of such building types during strong shaking. Owing to paucity of data, buildings have been broadly classified into residential and nonresidential types based on functional use mainly due to wide variation of occupancy characteristics between these two broad occupancy categories during day and night time.

PAGER Specific Inventory Needs

In order to estimate building damage and related casualties due to an earthquake anywhere in the world, it is essential that the building types, their distribution within a country or region, and their average occupancy during day and night time be determined. PAGER utilizes the population exposure as derived from the Oak Ridge National Laboratory's LandScan 2005 database (e.g., Dobson, Bright and others, 2000; Bhaduri, Bright and others, 2002) as the basic input for estimating the likely number of people exposed to variable ground shaking in terms of different ground motion parameters (e.g., peak acceleration, velocity and spectral response parameters). The derivation of ground motion shaking distribution is computed using ShakeMap system (Wald, Worden and others, 2005). Within the framework of the PAGER semi-empirical (Jaiswal and Wald, work in progress) and analytical loss models (Porter, 2008), the following are the broad requirements related to development of global building inventory:

1. The fraction of each dwelling type by occupancy (based on functional use),
2. Occupancy (number of people per facility class during the day, night and transit time) characteristics, and
3. The fraction of PAGER model building types (construction types based on structural systems) for each occupancy class.

Building inventory classification allows us not only to differentiate buildings with substantially different structural characteristics but also to group them based on availability of raw data. The available data could be in the form of predominant construction material used or model building types distribution compiled through engineering surveys or expert opinion. Ideally, each model building type and its vulnerability characteristics would be ascertained, giving the fraction of each model building type in a region. HAZUS classifies the entire building stock within the U.S. into 36 model building types, yet estimation of the inventory for each of the model building type is not based on actual data but has been derived based on very general tax assessment and housing census information. The model building types used within HAZUS are conditioned to only U.S. building designs and construction practices and therefore cannot be used for classifying inventory in developing countries of the world, where construction practices are significantly different. For the PAGER loss methodology applications, building inventory distribution needs to be mapped into PAGER model building type taxonomy as shown in Appendix I.

Methodology

The PAGER inventory development was divided into three phases:

1. Database identification, preparation and confidence rating,
2. Data aggregation and quality ranking, and
3. Data assignment for missing entries.

Figure 2 provides an overview of the proposed inventory development methodology for PAGER development. The inventory development procedure described in following subsections is based on housing unit fractions rather than building fraction of particular structure type. Some of the data sources such as, published literature or WHE data provide building inventory distribution by building rather than dwellings. In such cases, we have identified them separately and converted into fraction of dwelling stock by equivalent number of units or by volume, rather than its number for the PAGER inventory distribution.

Phase I: Database Identification, Preparation, and Confidence Rating

Phase I constitutes a search of all the country-specific available information from various identified inventory data sources and processing of the raw data through attribute mapping and assigning qualitative ratings to each data source to be used for later phase of inventory development.

Data Identification

We first identified all available data sources that could provide useful information related to the PAGER building inventory development (the WHE database, UN Housing database, published literature or reports, individual country housing information) as shown in figure 3. The selection of the data source is based primarily on whether or not the data provide either occupancy characteristics or construction type information, at least at the country level.

Geographic Location and Resolution

After selecting a database, we confirmed that the database provided appropriate geographic coverage. If data were only available for sub-country regions, in some cases they were used as a proxy to represent a particular country, but that assumption was reflected by a lower confidence level assignment used in the inventory model. For example, post-earthquake or scenario earthquake studies, for which the distribution of construction types or occupancy characteristics were obtained via field surveys (Faccioli, Pessina and others, 1999; Ozmen, 2000; Tien, Juang and others, 2002; Tobita, Miyajima and others, 2007), were sometimes considered to be reliable and generally applicable to the country as a whole, particularly in the absence of country-level data. Data that did not contain country-specific information or that do not help in making country specific expert judgment were discarded at this stage.

Occupancy Classification

The occupancy-specific information needed for the PAGER inventory model is generally categorized in terms of residential, nonresidential or outside (for example, people in transit and not subject to casualties due to potential collapse of buildings) as a function of the time of day. If the database provides information about the fraction of people in each of these three occupancy categories, then the data are used directly. In the absence of such specific categorization, certain predefined classification schemes based on engineering judgment are used to convert the raw data into the equivalent three occupancy categories. For example, the fraction of people working in various types of facilities, such as administrative, commercial, banks, academia, and other facilities with similar usage, given in the database were classified into the nonresidential category, whereas people residing in single or multi-family dwellings could be grouped into the residential category. The fraction of the population that does not belong to either type is broadly termed as outside. Since most of the databases do not have occupancy defined as a function of the time of day, it is necessary to apply this correction separately to each occupancy category during the inventory development. Note that most of the databases that have been identified for PAGER inventory development provide only residential building stock data. However, the inventory methodology discussed in the present investigation is not limited to compilation of only residential inventory. It is planned to develop nonresidential building stock distribution by construction type in a subsequent stage through WHE-PAGER project for inventory development.

Data on day-time population of commercial or industrial buildings, or any other nonresidential buildings, are not available for any of the countries. The residential building inventory database to be developed here is targeted towards estimating fraction of occupants living in the residential dwellings. However, the exact fraction of the population which is not part of residential buildings especially during the day is not available. In order to estimate fraction of people living in any other unit or outside other than residential (which can be commercial, industrial or in transit) housing units during the day, we may need to estimate the total work force (labor force) in each country and then assign the fraction of the work-force population into nonresidential and outside.

We first compiled the data on average occupancy (number of persons) per dwelling irrespective of the construction type in different countries from several databases such as UN (2001) and UNECE (2006) as shown in Appendix II. In order to estimate the fraction of people not residing in residential dwelling during work hours, we calculated the work force population from EUROSTAT (2006), the CIA-FACTBOOK(2007), and developed an estimate of fraction of the population in the workforce as shown in Appendix III. Details of estimating fraction of population by time of day in three different occupancy categories (residential, nonresidential and population at transit) are described in (Jaiswal and Wald, work in progress).

This database could be used to estimate the likely average number of dwellings in each geographic region based on population data from the Oak Ridge National Laboratory's LandScan 2005 database (e.g., Dobson, Bright and others, 2000; Bhaduri, Bright and others, 2002). The average number of people per construction type is derived from the WHE housing type database and the ATC average occupancy estimation procedure as shown in Appendix VI.

Construction Type Classification

An important and challenging effort required for PAGER inventory development was the identification of data sources that could provide information about various construction types and the fraction of people residing in each type for a given country. Ideally, construction types could be classified according to their structural system, load transfer mechanism, predominant construction material used, and performance during past earthquakes. However, most of the inventory data that have been identified during the inventory development efforts did not provide building-specific information; hence it was necessary to adopt broad construction type classification based on material used for the construction of walls and roofs. This is similar to the classification used by most of the housing census and surveys carried out for a large number of countries in the past. More details about construction type classification are given in Appendix IV.

Average Occupancy by Construction Type

Earthquake casualty estimates are dependent on the fraction of people residing within each building type at the time of the earthquake. A typical wooden single family dwelling has a much lower occupancy than a large multistory, reinforced-concrete apartment building. Hence it is necessary to estimate the average number of occupants in a particular building type to estimate the likely casualties after an earthquake.

Typical occupancy information by construction type could be estimated by utilizing the data developed from Appendix I along with inputs from WHE reports (EERI, 2007) and region-specific published literature wherever available. However in the present report, only the WHE forms have been used to deduce the average occupancy of a construction type by time of day (day or night).

Because data are so limited, it is necessary to deduce such information by utilizing the average person per housing unit available from the UN database along with engineering and demographic judgments to estimate occupancy information. We first mapped the WHE housing types to PAGER structure type category as shown in Appendix V. We then assigned an estimate of occupancy pattern for PAGER structure type using the most commonly described occupancy pattern given in WHE database for a particular structure type. For the PAGER structure type where WHE database does not provide occupancy-related information, we used expert judgment based on height, as well as structural system information from similar construction type in the WHE database, to assign likely occupancy pattern. The mapped occupancy pattern for PAGER structure type is shown in Appendix VI, and it can be used for countries where occupancy-specific information is missing.

Attribute Rating

Once the selected database is processed for these three specific attributes, we assigned ratings for each based on predefined PAGER attribute rating criteria (High, Medium, or Low) and rated all the entries in a given database. "High" quality refers to data compiled after engineering or telephonic surveys; field visits for ground-truth or data compilations from local engineering experts; "Medium" quality refers to data compiled by general field survey and assignments generally not based on engineering standards, and "Low" quality refers to data compiled by non-engineering agencies and is not specifically meant for engineering loss analysis.

Any missing information is assigned with "Null" whereas all useful information is entered using the PAGER attribute mapping scheme. After rating, we verified each data entry for possible errors or duplication and repeated this procedure separately for all possible PAGER inventory databases that contribute useful information. At the end of this phase, each raw data source, alongwith the relevant information contained therein, was identified, rated, and compiled for further processing in Phase II.

Phase II: Data Prioritization, Merging, and Country Assignments

As shown in figure 4, Phase II consists of the development of single inventory matrix that covers the structure and occupancy related information at the country level by selecting the best quality attributes from the various individual databases processed during Phase I of the PAGER inventory development.

Selection of Attribute Assignments Using Ratings and Vintage of Data Source

For each country, if only a single database provides information for a certain attribute, we assign it directly in the PAGER inventory matrix along with its rating. If none of the databases provide information for certain attribute of a country, we assign the missing information based on an *a priori* country pairing described in the next section. If multiple databases are available for a particular country and attribute, then selection of appropriate attribute assignment is carried out in a two-step process according to both its rating and vintage. We sort the attribute assignments according to their rating and select attributes that have higher rating. In the case of a particular attribute for a chosen country that has multiple databases assigned the same rating, we sort the assignments according to database vintage, retaining the most recent data. If attributes with similar ratings and vintage exist, we chose the attribute based on heuristics i.e., published literature data supersedes World Housing Encyclopedia reports or expert judgment surveys and UN-HABITAT

(2007) data supersedes UN (1993). The outcome of this exercise is selection of a single attribute assignment for a chosen attribute type and country.

Attribute data with "Null" or missing entries are carried forward for further processing in the Phase III procedure. The output of Phase II consists of a single inventory database matrix compiled from several individual data sources based on PAGER prioritization and classification criteria as shown in figure 5.

Phase III: Data Development for Missing Entries and Synthesis

The main objective of this phase is to fill out all the non-exhausted attributes ("Null" entries). This is done either by assigning all the PAGER attributes for a particular country based on predefined criteria (deduced normally from attributes of a neighboring country) or by assigning a regionally consistent attribute-specific judgment due to lack of specific information in the available databases. The following are the steps involved in filling up "Null" entries.

Missing Entries and Country-Pairing

For each missing entry of the inventory matrix, we first verify whether any regional estimates are available for the missing attribute. Regional estimates may be in the form of data published in research articles or reports applicable for a group of neighboring countries where the available estimates could be used as a proxy. Earthquake source-specific or regional scenario-based loss estimation studies are generally performed by researchers to understand the potential of future large earthquakes and its impact on human built environment. Such studies make use of localized survey or expert judgment to develop broad understanding of building inventory distribution of a region under consideration. Although these data may or may not necessarily reflect country-level loss estimates, in absence of any additional information, such peer-reviewed inventory estimates can be used for replacing missing data for those countries.

Despite the use of several data sources during PAGER inventory development, more than 50 percent of countries across the globe have no direct information about building inventory distribution (fig. 4). This step is aimed to develop first-order estimation of distribution of housing types in countries that have no information available. In the absence of any regional data or inventory of other loss estimation studies for the region/country, we needed an approach that could assign the missing data for countries through similarities of demographic and economic characteristics, construction practice in the neighboring countries, and also performance of facilities during past earthquakes to base our engineering judgments for country-pairing. Porter and Jaiswal (2006 unpublished report) compiled a first order vulnerability ranking scheme by which to group countries or a geographic regions of the world were classified into 5 vulnerability regions. Each of the vulnerability regions was assumed to have relatively uniform vulnerabilities independent. The building stock and infrastructure belonging to region 1 was assumed to be the least vulnerable (e.g., California, New Zealand) region 5 countries were highly vulnerable (e.g., Afghanistan, Iran). The basis for the regionalization was based on building codes and code enforcement. Countries with few inherently lethal pre-code buildings are assigned region 1. Locations with poor-engineered construction are assigned region 3. Adobe and rubble masonry being among the most lethal types, locations where these types predominate are assigned 5. Levels 2 and 4 are intermediate. Although the scheme is broad, non-quantitative and based on subjective judgment, it is being used only to select the best neighboring country for assignment of building inventory. It is quite common to have similar construction practice and building characteristics among neighboring countries that have similar population growth pattern, lifestyle, and social and economic characteristics. We compiled a list of countries that have no data on building inventory and developed country-pairing criteria to replace missing elements with known information from neighboring countries.

PAGER Inventory Matrix Compilation

Among all the neighboring countries, we selected the country that has same PAGER vulnerability region code (Porter and Jaiswal, 2006 unpublished report) as the vulnerability of missing country. If there are no countries with the same vulnerability code and or more than one country with the same PAGER vulnerability code, we use the data from the country that has highest rating (fig. 6). In the case of countries that have the same ratings, we selected the neighbor that has most recent data (fig. 7 & 8) and replace the data of the missing country element with the information from the chosen country. After completing the first-level exercise of identifying the neighbors that have the highest quality data and which share a common boundary with the missing country, several countries remained with no immediate neighbor. In such cases, we used expert judgment to identify the country from the region (without common boundary) that had the highest quality and most recent data. Finally, we used the procedure described in the previous section to replace all the missing attributes of inventory matrix of a particular country and then repeated the procedure for all the countries to replace all "Null" entries for the final PAGER inventory matrix as shown in figure 9. The outcome of Phase III procedure is a single PAGER inventory matrix with the three PAGER attributes, namely occupancy distribution, construction type distribution, and occupancy by construction type for all the countries of the world. Appendix VII (also available as an electronic supplement) shows a country-level PAGER inventory database compiled in terms of fraction of PAGER structure types for each country along with the source, rating, and vintage of the database.

Limitations of the Methodology

The methodology discussed in the previous section for our global inventory development for the PAGER project is similar to the ATC-13 and HAZUS inventory development apart from its global coverage and aggregation for the types of attributes involved in the inventory development. The three-phase methodology described in this investigation is relatively new and largely untested. Hand checks were done for certain attributes at the country level and QC/QA procedure adopted during data development. However, some modifications in terms of the choice of attributes, low geographic resolution for certain countries, and attribute mapping are likely to be required. Many assumptions such as the choice of attributes and their mapping were based on engineering judgment followed by limited Internet research (in terms of photos or specific reports of housing types for a particular country). For example, figure 10 shows a typical wood construction in Bangladesh. These assumptions could be improved upon through sampling of actual facilities or by conducting engineering surveys. Although the methodology is designed to work for a global inventory, users should be aware of the limitations of the methodology and be on the alert for obvious discrepancies in the raw or processed inventory data.

The inventory developed using this methodology is generally dependent upon the raw data sources. The quality and accuracy of individual raw data sources and its interpretation during inventory development will become increasingly unreliable for resolutions finer than the country level unless more refined geographic regions are identified. Rapid growth of urban centers, particularly in developing countries, could result in significant variations of construction practice, choice of construction type, urban planning, and unbalanced demographic and social characteristics (fig. 11). As the inventory developed in the present investigation is open for review and modification, these limitations are bound to diminish as more data become available at higher resolution.

Illustration of Inventory Data Compilation for Peru

This section illustrates the housing stock attribute grouping assignments and compilation of the inventory data for a chosen country, Peru. The following data sources were consulted:

1. United Nations housing database
2. UN-HABITAT (2007) DHS database
3. Population and Housing Census
4. World Housing Encyclopedia (WHE) housing type reports
5. Published Literature about housing/building stock

United Nations Housing Database

As shown in figure 12, the housing related information is limited to the knowledge of material of construction of external walls of a housing unit for Peru. The nomenclature used herein (such as, waste, other) is not explicit and consistent, which makes it difficult to collate directly to particular structure types. We mapped this distribution to PAGER structure type using assumptions as discussed in Appendix IV. About 31.1 percent housing units in Peru have been constructed using bricks for wall construction. However, brick could also be used as a potential building material for construction of infill masonry walls in reinforced concrete or steel-framed constructions. Similarly, timber-framed structures also commonly utilize brick-veneer as a cladding material. Since the original data do not clearly indicate the fraction of each of these categories, we conducted a literature search for housing construction in Peru and found that most of the constructions in Peru were constructed using non-engineered weak masonry structures with brick as the construction material (fig. 13). We avoided any expert judgment in evaluation of the fraction of units of different categories in this phase of inventory compilation and tried to directly use original input from the source for mapping. Hence this fraction of housing units have been classified as unreinforced fire-brick masonry (UFB) category and similarly, the 7 percent fraction of housing units which are made of wood have been mapped to general timber construction (W) category. Since no specific details are available about “Waste” or ”Other” type material, we have classified this housing stock to be of informal constructions (INF) category.

UN-HABITAT (2007) DHS Database

The demographic and health survey dataset compiled by UN-HABITAT provides data for Peru, collected in 2004, and shown in table 7. The raw descriptions of the wall materials are quite difficult to map with the conventional terms used for describing the material of construction. Again, some background literature search and Internet research were beneficial in understanding each description, allowing us to map them to PAGER construction types, as shown in Appendix IV.

Population and Housing Census

The National Institute of Statistics of Peru conducted a 2005 round of population and housing census surveys, covering around 27 million persons and approximately 7 million homes, respectively (*http://unstats.un.org/unsd/demographic/sources/census/perupdf.pdf*). However, the official data about census of housing by construction material were not available online to access and utilize for inventory development.

World Housing Encyclopedia (WHE) Reports

For Peru, the World Housing Encyclopedia (WHE) Web site (*http://www.world-housing.net/*) provides three housing type reports, namely, confined masonry buildings; confined masonry houses, and adobe houses (EERI, 2007). Each of the reports provides detailed information about housing characteristics, construction practice, occupancy (average number of people per housing unit/building) and other social and economic aspects. Unfortunately, none of the reports for Peru cover the inventory information for the specific housing types as required for PAGER inventory database. Because of the lack of specific information, the WHE database could not be utilized as possible input for inventory compilation for Peru.

Published Literature of Housing/Building Stock

The June 23, 2001, a magnitude 7.9 earthquake near the southern coast of Peru caused serious damage and casualties. There was widespread damage and 102 people were killed, 1,368 were injured, and 11,043 houses were destroyed, primarily in the vicinity of the provinces of Arequipa, Moquegua, and Tacna. The survey conducted by the Building Research Institute of Japan found three main housing types in rural areas: adobe, sillar blocks, and brick-masonry construction (Kusunoki, 2002). According to the report, nearly 80 percent of housing in the San Francisco district was made of adobe and most of these dwellings suffered damage during the earthquake. The EERI reconnaissance study, conducted after 2001 earthquake (EERI Special Earthquake Report, 2001), indicated that the housing in the urban areas were mid-rise reinforced concrete buildings with infill-masonry walls or shear-wall construction. The 2007 Peru earthquake caused widespread damage to non-engineered structures commonly found in urban and rural areas of Peru;this includes traditional earthquake structures (adobe), masonry structures and RC frames with infill masonry but not designed for earthquake loading (Taucer, J. and others, 2007). However, none of the published literature provides specific information regarding either structure type's distribution or the general building stock distribution for Peru.

A Review of the above data sources for inventory information for Peru clearly shows that although Peru is an earthquake prone country, the knowledge of building inventory is severely limited. The most recent information available concerning building stock for Peru is that of UN-HABITAT, and it was assigned a "Low" quality rating in the PAGER inventory database. Figure 14 shows the inventory information solicited from expert survey under the WHE-PAGER project that has been used to replace the inventory information of UN-HABITAT database. Various building type descriptions from expert judgment have been mapped to PAGER structure types. (M-Mud wall construction, C1- Concrete moment framed constructions, C2- RC shear-walled and dual framed constructions, C3- Concrete moment frame designed for gravity loads, UFB3- Unreinforced fire brick masonry with lime mortar and RM2- reinforced or confined masonry constructions).

Inventory Compilation for Selected Countries

This section provides several step-by-step examples of the procedure adopted for compilation of housing stock inventory for selected countries.

Australia

Except for a few regions such as Newcastle/Lake Macquarie, most of Australia faces relatively low seismic hazards compared to more seismically active intra-plate regions of the world (Edwards, Robinson and others, 2004). However, in contrast to most stable continental regions, where the largest magnitude earthquakes ($M > 6.0$) are concentrated in failed rifts or passive margins, Australia's largest onshore earthquakes have occurred mostly in the ancient Proterozoic and Archean terranes of western and central Australia (Johnston and Kanter, 1990).

Information about nationwide building inventory in Australia is quite limited. However, a recently launched project by Geoscience Australia (Nadimpalli, Cornish and others, 2002) aims to develop a nationwide building exposure database compiling data from various agencies such as the Public Sector Mapping Agency (PSMA) and the Australian Bureau of Statistics (ABS). The housing type data from Australian Bureau of Statistics in 1986 compiled by (United Nations, 1993) indicated that about 76.7 percent of dwellings in Australia were separate homes, whereas 13.6 percent were other medium-density dwellings, and 2.2 percent belonged to semi-detached houses. The information about construction characteristics was not available from any of the UN databases even in their recent compilations.

We compiled the data from census of housing and population in their most recent census survey for Australia through written communication with Geoscience Australia (Edwards, written communication). The original housing census information is rigorous (by wall and roof/floor material) and has high spatial resolution with estimates of total dwellings by roof and wall construction material for each geographic region/census division of the country. However, we combined the regional distribution to country-level in the present inventory development effort using distribution of dwellings by construction material of the outer walls. The main construction materials described are double brick, brick veneer, timber, and fibro/asbestos cement, all of which have been mapped into the PAGER construction type categories (as shown in table 8) using engineering judgment. Our mapping is similar to the earlier mapping scheme suggested and used by Edwards, Robinson and others (2004) in their inventory development.

El Salvador

Most of the historical earthquakes in El Salvador originated along the Central American volcanic chain within the upper crust of the Caribbean plate (White and Harlow, 1987). At least dozen of earthquakes since 1710, mostly upper-crustal located in the San Salvador area, have caused damage in the city.

The 1986 San Salvador earthquake (M_w 5.7) caused severe damage in the city of San Salvador (Harlow, White and others, 1993). It was estimated that 60 percent of the population of San Salvador (about 1,500,000) lived in marginal settlements and many of the structures had extremely poor earthquake resistance. The construction practice in the region had been strongly influenced by Spanish colonization and remained practically unchanged until the 1940s. Lara (1987) provide detailed descriptions of the construction practices in the San Salvador region. The construction type distribution compiled by INTERTECT after the earthquake indicates that about 15 percent of the buildings were of wood; 10 percent made of block masonry; 37 percent constructed using traditional brick masonry construction; 37 percent of wood frame with poor infill walls (Bajaraque); and 1 percent of adobe construction (INTERTECT, 1986). According to Shiono and others (1991b), the survey conducted by INTERTECT was limited to established residential areas of the affected region, and extremely inferior dwellings were not included in the estimation. We have mapped the housing stock distribution using the (Shiono, Krimgold and others, 1991b) survey as shown in table 9.

Indonesia

Indonesia has experienced several catastrophic earthquakes including the 2004 M_w 9.0 and 2005 M_w 8.7 Sumatra – Andaman Islands earthquakes, and the 2006 M_w 6.3 Yogyakarta earthquake in the recent past. The building stock in Indonesia performed extremely poorly during recent earthquakes in the country. A total of 156,662 housing units were totally destroyed whereas 202,031 have suffered damage during the Yogyakarta earthquake in 2006 (BAPPENAS Report, 2006). The four rural districts of Bantu, Klaten, Sleman, and Gunung Kidul suffered more than 91 percent total housing destruction despite this moderate-sized (M_w 6.3) earthquake. According to the reconnaissance study carried out by the Mid-America Earthquake Center (Elnashai, Kim and others, 2007), the high level of building damage was mainly due to poor construction techniques, lack of seismic design provisions, and high population density in the region (1,600 persons/km^2). Rural Indonesia is dominated by traditional one-story, unreinforced clay brick/block masonry in cement or lime mortar. The unreinforced clay brick, stone masonry walls support the timber roof system and transfer the load to random rubble stone strip or isolated footing. There is no adequate connection between timber roof frame and masonry walls. Most of the housing in urban areas in Indonesia is low to mid-rise reinforced concrete frame buildings with infilled masonry walls. These buildings have performed quite well and buildings of these types in Banda Aceh suffered only minor damage during the 2004 Indonesia earthquake (Saatcioglu, Ghobarah and others, 2006). The housing stock distribution compiled for PAGER inventory database is shown in table 10.

Iran

Iran has experienced many deadly earthquakes in the recent past which have resulted in huge casualties for example, 1962 M_s 7.3 Buyin-Zara; 1968 M_s 7.3 Dasht-e Bay z; 1972 M_s 6.9 Ghir; 1976 M_w 7.0 Iran-Turkey border; 1978 M_w 7.3 Tabas; 1981 M_w 7.2 Sirch; 1990 M_w 7.4 Manjil; 1997 M_w 7.2 Ardakul; and 2003 M_w 6.6 Bam. This highly seismic region forms the north-west trending boundary between the Arabian and Eurasian tectonic plates. The combination of high hazard and primarily poorly constructed adobe structures makes Iran an extremely high-risk country. UN data for Iran (1986) indicates that around 28.9 percent of housing units are adobe and more than 43 percent are made of clay brick masonry constructions (United Nations, 1993). Though this information is coming from the UN compilation for global housing, due to limited engineering input and the lack of professional engineering surveys in the development of these data requires us to assign a low quality rating to this data.

A study conducted by Ghafory-Ashtiany and Mousavi (2005) after 2003 Bam earthquake indicated that about 84 percent of buildings (including 93.1 percent of adobe buildings) were built prior to the institution of seismic codes in Iran in 1991. After the Bam earthquake in 2003, around 650 buildings were surveyed, primarily steel and reinforced concrete buildings that survived (Moghadam, 2005). The damage statistics show that about 65 percent of buildings were single-story and most of the surviving buildings had masonry solid brick walls as partitions or bearing walls. As per the 2005 census (Iran Statistical Year Book, 2005), 10 percent of the dwellings have metal construction, 4 percent have reinforced concrete construction, 45 percent are brick and steel, 14 percent are brick and wood, 6 percent are cement block and 20 percent are not stated (fig. 15). We used this data as a proxy representation of housing type distribution in both urban residential and nonresidential and rural nonresidential areas of Iran with “Medium” rating. According to Ghafory-Ashtiany and Mousavi (2005), about 40.6 percent buildings were made of brick and steel, 1.9 percent were of brick and wood, 3.5 percent brick only, about 53.2 percent were of adobe (sun dried brick and clay) and 0.8 percent as concrete constructions. It is evident that large fraction of building types in Iran are non-engineering adobe or brick masonry construction. We used the inventory distribution suggested by Ghafory-Ashtiany and Mousavi (2005) for Bam and surrounding area as a proxy housing inventory especially in rural residential areas of Iran with a “High” rating as shown in table 11.

Italy

Primary tectonic activity in Italy results from the collision between the Eurasian and African plates. The high-topography zone of the central Apennines, which trends NW-SE within peninsular Italy, is dissected by a Quaternary fault system that has hosted several moderate to large historical earthquakes (Cello, Mazzoli and others, 1997); most recently the 1980 M_w 6.9 Iripinia; and the 1997 M_w 6.0 Umbria-Marche events. In 2002, the Molise and Puglia regions of southern Italy were struck by two moderate-magnitude earthquakes (Cara, Rovelli and others, 2005). The first and larger of the two (M_w 5.7) resulted in 30 casualties in the town of San Giuliano di Puglia. A scenario based damage study carried out by Faccioli, Pessina and others (1999) for residential buildings in the city area of Catania indicated that there are several limitations with the inventory data available from nationwide census of dwellings, or ISTAT (Italian Institute of Statistics). The authors used CONARI survey (a database which compiles information about buildings in the central city area of Catania) for their damage scenario study of Catania city (Faccioli, Pessina and others, 1999). This database was compiled based on a survey of buildings carried out by the Catania city planning office in late 1980s but it was limited to the central area of the city. The authors also discussed some results from an ongoing ad hoc local survey (also called LSU survey) of all buildings in the city. Recently Dolce and others (2006) conducted a vulnerability assessment and damage scenario study for Potenza (southern Italy) using the inventory data compiled from engineering surveys carried out after the 1990 earthquake that struck Potenza (the data were subsequently updated in 1999). The Potenza inventory indicates that about 62.1 percent of buildings are unreinforced masonry construction, about 36.3 percent are made of reinforced concrete framed buildings and 1.3 percent of other categories, but mainly steel construction. The authors classified this distribution in subsequent tiers of structural systems based on both volume of construction and the number of buildings. It is evident that the building stock in southern Italy, which is most prone to earthquakes, is an important dataset geographically for Italy and is used as a representative distribution for the whole of Italy for PAGER purposes. We have used the inventory distribution suggested for Potenza because this development was based on more detailed analysis of the inventory data by the authors, based on local construction and engineering design knowledge and also interpretations from other data sources and engineering surveys. We have mapped the distribution of building types by number into equivalent PAGER construction types using engineering judgment as shown in table 12.

Japan

Japan is a densely populated nation with high seismic hazard. Much of Japan’s population resides on thick sedimentary basins that have significant potential to amplify ground shaking. Tectonically, Japan is located near the junction of the Pacific, Philippine Sea and Okhotsk tectonic plates. The Pacific plate is moving northwest at a rate of about 8-9 cm/yr relative to, and subducting beneath, the Philippine Sea and Okhotsk plates. In addition, the Philippine Sea plate is subducting northward beneath Japan and the Okhotsk and Amurian plates (Miller and Kennett, 2006). The complex tectonics drive the high rates of seismicity observed in the region, and the subducting slabs provide the source for the many active volcanoes that occupy the island.

The housing and land survey conducted by Japan Bureau of Statistics is the most fundamental statistical survey on housing (Statistics Bureau Japan, 2003). The focus of the 2003 Housing and Land Survey was dwellings, other occupied buildings, and all the households inhabiting those dwellings and buildings which were located in the enumeration unit districts at the time of the 2003 Housing and Land Survey. The data for Japan, Prefectures, and 14 major cities indicate that 31.7 percent of dwellings are of wooden constructions without fireproof protection, and 29.7 percent are wooden with fire protection. About 31.9 percent of the total dwellings are made of reinforced concrete constructions and 6.4 percent are of steel-framed construction. Most of the reinforced concrete-framed and steel-framed construction in Japan is relatively new and has been constructed after 1980. We have used the housing unit distribution available from Housing Census of 2003 for inventory compilation as shown in table 13.

Mexico

Mexico is situated on the boundary between large tectonic plates and is prone to frequent large earthquakes. It has a long history of destructive earthquakes. In September 1985, an earthquake measuring 8.1 and centered in the subduction zone off Acapulco killed more than 4,000 people in the Mexico City, even though the city was located more than 300 km away from the epicenter of the event.

The 1990 round of census data of population and housing in Mexico indicated that about 69.9 percent of housing units were made of brick or stone block, 14.7 percent were made of adobe, 8.2 percent of wood, and 7.2 percent of other materials. The most recent data from INEGI estimates about 75.7 percent of masonry construction (blocks, stone, or brick) and 24.3 percent of other wall materials. About 59.8 percent of these constructions had concrete or Tabique roofs, and 40.2 percent had other nonclassified material, as shown in table 14.

Nepal

Geologically Nepal is situated on the boundary between the Indian and Tibetan plates. The Indian plate is continuously moving (subducting) under the Tibetan plate at a rate thought to be about 3 cm per year. The existence of the Himalayan range with the peak of Mount Everest is evidence of the continued tectonic activities beneath the country. Historically Nepal has witnessed several devastating earthquakes. The great Bihar-Nepal earthquake in 1934 was the most severe in recent times, killing more than 8,500 people and damaging approximately 80,000 homes.

The data obtained from National Living Standards Survey (2003-04) indicates that about 47.5 percent of households in Nepal are constructed using mud-bonded bricks or stones as the construction material for outer walls, whereas 18.5 percent are constructed using wood and approximately the same fractions have cement-bonded brick or stone walls with concrete roofs. There are around 15 percent households with largely informal materials; this fraction goes higher for the eastern part as compared to the western part of Nepal where wooden construction is more commonly used (Nepal Central Bureau of Statistics, 2004). About 32.3 percent of the housing units have straw or thatch roof; approx. 30 percent slate or tiled roof; 21 percent with galvanized iron (GI) sheet; and 13.6 percent concrete roof, as shown in table 15.

New Zealand

New Zealand straddles the boundary between the Indo-Australian and Pacific tectonic plates. The relative plate motion in New Zealand is expressed by a complex assemblage of active faults, coupled with a moderately high rate of seismicity (Stirling, McVerry and others, 2002). The plate boundary beneath New Zealand comprises the Hikurangi (North Island) and Fiordland (far south of South Island) subduction zones, which dip in the opposite sense relative to each other. Active tectonic motion is accommodated by the faults of the axial tectonic belt that traverse much of the South Island between the subducting slabs (Stirling, McVerry and others, 2002). The Alpine fault in the central South Island accommodates the release of much of the strain energy produced by the relative plate motion.

Recently, a reconnaissance report following the M_w 6.5 1987 Edgecumbe, Bay of Plenty earthquake indicated that most of the damage occurred on drained swampland consisting of soft, unconsolidated soils (EQE, 1987). Based on these observations, the effects of site response are important to consider in hazard and risk assessments in regions such as New Zealand.

The housing and population census data for New Zealand in the 2006 round indicate that 58.4 percent of occupied dwellings in the country are separate single story houses, whereas 17.7 percent are separate houses with two or more stories. About 10.2 percent of the dwellings have been classified as apartment or townhouses with two or more flats with single story, whereas only 5.52 percent have two or more stories (New Zealand's Official Statistical Agency, 2006). The distribution of dwelling stock by use of construction material for the outer walls was inaccessible from the Web source. Our estimates for the housing stock distribution for New Zealand were primarily based on Dowrick (1998) and are shown in table 16.

Taiwan

The high seismicity in Taiwan results from the convergence of the Philippine Sea plate and the Eurasian plate. The Philippine plate is moving northwestward at a rate of about 7 cm/yr relative to the Eurasian plate.

Although not abundant, mud brick residences are a special and traditional type of construction in Taiwan. This is mainly due to easily available, cost-effective construction material and weather conditions in the region, as this type of housing provides heat insulation (warm in winter and cool in summer) for the occupants. At the time of the magnitude 7.7, Chi-Chi earthquake (1999), though the number of mud-brick residences comprised only 5 percent of the total building stock in Taiwan, about 43.5 percent of the total casualties were attributed due to collapse of mud-brick houses (Tien, Juang and others, 2002). Another common building type in Taiwan urban areas is reinforced concrete (RC) buildings with infill masonry constructions. About 18.6 percent of total victims died from the collapse of high rise (generally 10-15 stories) RC buildings, and 16.4 percent died in buildings which are shorter than 6 stories. The two most common housing types in urban areas are reinforced masonry buildings and RC buildings. Yao and Sheu (2002) and Tung and Yao (2002) provided more detail about such construction and its vulnerability to recent Taiwanese earthquakes.

Although the information regarding total housing stock distribution in Taiwan exists in the form of householder registration data, it was not accessible to us for use in developing building inventory. Nevertheless, the housing stock distribution for most of the affected areas after the Chi-Chi earthquake is well documented and gives detailed information. We compiled the building stock distribution available for Nantau and Taichung County (Tien, Juang and others, 2002) and normalized them using population data. The housing type description has been mapped with PAGER structure type, and the estimated inventory distribution for Taiwan is shown in table 17.

The Philippines

The Philippine archipelago represents a complex system of micro-plates that are being compressed between two convergent plate margins that bound the nation; the Philippine Sea and Eurasian plates (EQE, 1990). Because of its tectonic setting, the Philippines experience frequent damaging seismic activity. The census of housing conducted by National Statistical Office of Philippines in the year 2000 round estimates 30.8 percent housing units of brick, stone or concrete walls whereas 22.7 percent are of wood among the occupied housing units in the Philippines. About 22.8 percent of the housing units in rural areas are of Bamboo/sawali/cogon/nipa, which is poor quality wood construction, and 18.9 percent of half wood and half concrete/brick/stone category. We mapped the construction material type to PAGER structure type and developed fraction of housing units by construction type as shown in table 18.

Turkey

Turkey is situated in one of the most seismically active regions of the world with a large part of the country at significant risk of major earthquake catastrophe. The region is tectonically active and experiences frequent destructive earthquakes. First-order tectonics is controlled by the collision of the Arabian plate and the Eurasian plate. A large piece of continental crust almost the size of Turkey, called the Anatolian block, is being compressed in a westerly direction. The block is bounded on the north by the North Anatolian fault and to the south east by the East Anatolian fault. Several region-specific efforts have been made by the researchers in Turkey to understand the building stock inventory and its vulnerability in the past. The assessment of proportion of buildings in each structure type category and its occupancy were based on several localized surveys after recent large earthquakes, either in post-earthquake damage or vulnerability studies (Bogaziçi University, 1992; EEFIT, 1993; Erdik and Aydinoglu, 2002). Bommer, Spence and others (2002) recently developed the earthquake risk model for Turkey under the Turkish Emergency Flood and Earthquake Recovery Program (TEFER) project. The development of inventory is based on classification of construction types, which in turn is based on vulnerability as observed during recent earthquakes. The authors also provided typical distribution of residential building stock assumed for some locations. Though the authors have not clearly indicated the location name or its spatial coverage, we believed that the distribution is generally indicative of overall rural and urban Turkish building stock (fig. 16). We mapped the original classification (both urban as well as rural) to PAGER structure type classification and used these most recent data for PAGER inventory development purposes (table 19).

Application to the Continental United States

Several earthquake-specific research studies conducted in the United States specifically for California have provided new directions in global earthquake hazard and risk understanding. ATC-13 (ATC., 1985) developed the first broad inventory database for California by compiling databases from several different sources. Later, FEMA (FEMA, 2006) adopted the inventory development methodology of ATC-13 and extended the effort to the rest of the United States for use in FEMA's earthquake loss estimation software HAZUS (Hazards U.S.). We adopted the inventory developed within the framework of HAZUS for the PAGER inventory database because it was developed through a rigorous, nationwide effort involving several different databases across the country. HAZUS's default building stock data cover residential, commercial, industrial, agricultural, religious, government, and educational buildings. The building inventory classification system developed for HAZUS consists of a two-dimensional matrix relating model building types grouped in terms of structural system to building occupancy classes. The PAGER regionalization scheme adopted for global earthquake casualty estimation classifies the United States into two broad regions, namely California and the rest of the United States (Porter and Jaiswal, 2006 unpublished report).

The ATC-13 project was one of the most rigorous efforts to compile the entire facility inventory for California. It was based on calculation of a matrix that relates Social Function Classification and Earthquake Engineering Facility Classification for each postal ZIP code in California. The element of a matrix associated with each ZIP code gives the percentage of the total building floor area derived from nine characteristics matrices, each of which was considered valid for a given combination of building ages (pre-1950, 1950-1970 and post 1970) and number of stories (low rise, 1-3 stories; medium rise, 4-7 stories; and high rise, 8+ stories). The primary database used for residential building inventory development was United States Decennial Population Census database, and a high-rise building database covering about 3,000 buildings in California (both residential and nonresidential) was derived from several individual data sources.

The HAZUS facility specific inventory development for California was based on similar principles. However, the HAZUS developers subsequently made alterations to the original ATC-13 classification scheme to reflect more updated inventory information (Kircher, Whitman and others, 2006). Some of the key changes associated with residential buildings include assigning all the single family residential housing in California to be 99 percent wood and 1 percent reinforced masonry constructions. The multi-family housing (RES3) replaced the 5 percent of Mobile Homes (MH) with wood (W1) category and other modifications made in terms of code level assignments. As the HAZUS inventory database was developed after rigorous State and national level efforts, we used the default HAZUS building inventory data compiled for California directly in our PAGER inventory development as shown in table 20.

As the building inventory was provided at the Census tract level, we combined the total building stock distribution first at the State level and then calculated a combined estimate for all the States (except California) to estimate the inventory for the rest of the United States.

Web Delivery of Global Inventory

A global housing database is practically nonexistent except for a few data sources that provide limited and generally inconsistent information about housing types and (or) their distribution. The inventory database developed in this report therefore provides a step forward not only to motivate the development of more refined databases with higher resolution but also to use more consistent approaches for their development. It is evident that the future housing data compilations should be based on uniform methodologies and nomenclature that can easily accommodate engineering-based rather than indigenous terms (which are often confusing and do not provide adequate information about their structural systems). This is especially important in cases where engineering professionals are not involved in the data compilation. In cases where the data compilation is based on engineering surveys, the definition of structure type should be consistent with international standards for the definition of construction types.

We plan to provide this database online in the form of electronic supplement along with this report so that engineers and professionals from individual countries or international experts can view the data online and can suggest appropriate modifications based on the latest research conducted or expert opinions in their respective countries. The feedback received from respective country experts in terms of new data or modifications to the original data would be utilized to upgrade the default PAGER inventory database.

Implementation Challenges

Processing of Raw Data

One of the key challenges we faced during processing of raw data available from different sources was the variable format in which they were available. Most of the data were available in either paper or digital form but variable formats such as HTML, spreadsheets, published literature in scanned PDF (Adobe) reports were also common. Hence significant manual effort was required to bring these into digital format. Raw data have been processed into an appropriate form using a standard attribute mapping scheme specific to the data source, as discussed in previous sections.

Construction Type Mapping

We have observed that the nomenclature used for the description of construction types varies for different data sources and often varies from country to country. As most of the housing survey exercises are not conducted by engineering professionals, the descriptions of construction types from the census need to be used with caution. A typical case is when material used for construction of the building façade is interpreted as wall material, leading to an incorrect representation of construction types for that building. However, it is not possible to correct this in the basic data that are available for that country. Essentially, we need better mapping by local experts to either collate or segregate the original class of housing types into PAGER defined or other standard construction type definitions. As discussed in previous sections, we conducted limited Internet-based, country-specific research and reviewed the published literature for examples to identify common building types and construction practices; however, this approach could be further improved with additional information sources.

Occupancy by Construction Type

PAGER requires structure-specific occupancy information to estimate the likely casualties due to structural collapse or damage. The WHE database (EERI, 2007) is the only publicly available source that provides occupancy pattern by construction type (for some countries) as shown in Appendix V. Note also that average occupancy varies with time of day, day of week, and by type of occupancy (single or multi-family residential, commercial, or industrial). However, as discussed in the previous section, the PAGER loss methodology applies time of day corrections to estimate likely population occupying either the residential or nonresidential category. Hence, the likely average occupancy in each of these two broad categories needs to be estimated for each geographic region (country level).

Confidence Rating

Owing to large variations in the quality of data and types of data sources, it was important to rate the data sources based on unified approach in order to pick the right inventory information among several available sources. Confidence rating was solely based on the procedure adopted for collection of the data (ordinary versus engineering survey), purpose of the inventory data, and involvement of engineering expertise in the raw data development.

As discussed in the preceding sections, mapping of inventory distribution from one country to its neighboring country where data are not available entails additional uncertainties. Since such mapping has been carried out as a last measure and was based on limited research, we have therefore assigned “Low” rating to such mapping.

Limitations of PAGER Inventory Database

Housing Units and Building/Structure Type Inventory

A single building may have one or multiple housing units (single family dwelling vs. multi-family apartment buildings common in urban areas); hence the associated structure type distribution may change when we consider distribution of housing type against distribution of buildings for a certain country. Here we refer to the datasets that provide construction type data for housing units rather than of buildings. It includes most of the data originating from Housing Census surveys, the UN-HABITAT database, UN compilations (1993) and the EUROSTAT database. The dataset which provides structure type distribution directly for buildings are engineering surveys, world housing encyclopedia (WHE) database (EERI, 2007), published literature e.g., previous loss estimation studies in the region, loss modeling software (e.g., HAZUS in U.S., QUAKELOSS in Russian Federation, KOERIloss in Turkey, EQRM in Australia).

In order to have uniformity in the data development, we assign a unique identifier for the database that directly provides information about whether the dataset has building-specific distribution instead of housing unit distribution. We then estimate the likely PAGER structure type distribution corresponding to housing units based on the approximate number of units estimated from Appendix VI for each PAGER structure type. This estimation of approximate number of housing units by PAGER structure type is based on the World Housing Encyclopedia database. It represents the single largest compilation of housing data for more than 35 countries and is compiled by engineering and architectural professionals. Statistical extrapolation of such data beyond the specific country may or may not be very accurate. We believed such approximation to be necessary in the absence of any data, and the errors in such extrapolation may be of second order in terms of its impact on likely casualty estimation. However, future updates of the inventory database can help reduce such uncertainties in the inventory distribution.

Wall Material and Structure Type

The inventory database developed in this investigation is based on mapping wall material to PAGER structure types. Care has been given to follow the same mapping conventions across different data sources for similar descriptions. During mapping of the wall material descriptions, no subjective judgments were made to alter the original input data (in terms of fractions of units of certain wall material) to multiple structure types. Additional inputs from local engineering professional or loss modeling experts in a particular country may have provided better judgment in assigning one wall material type to certain structure types.

Vintage of Database

It is evident from the UN (1993) Housing Census data that for a few countries, the housing data compilation is much older than for the rest of the countries. Tremendous population growth followed by rapid urbanization in certain countries has influenced construction standards and practices. Similarly, seismic activity in a region can change the historical construction practice due to building code requirements. For example, URM or adobe constructions in certain countries are either significantly retrofitted or completely banned; substantial improvements in building code provision and its enforcement takes place in certain countries. However, the housing data do not reflect such changes, which can affect not only the inventory distribution but also the relative vulnerability of building stock and PAGER casualty estimates. It is extremely important that the inventory database developed herein be constantly updated and improved with input from local engineering professionals.

Resolution of Inventory Distribution

Except for a few cases, most of the risk or loss estimation exercises conducted around the world largely focus on “regional-level” risk or loss assessment. It can be in the form of a scenario of a major earthquake around a known seismogenic zone such as, Vrancea in Romania, Marmara in Turkey, New Madrid in the Central United States or to focus around a group of important cities or a city such as, Basel in Switzerland, Istanbul in Turkey, Tokyo in Japan, San Francisco in the United States, and Catania in Italy. The inventory database developed during such efforts are mostly applicable to smaller geographic regions and are not necessarily applicable to a country as a whole. Even though higher resolution inventory distribution for better regional risk estimation is extremely important, only a handful of countries have such information publicly available. At present, due to lack of data, the minimum geographic resolution selected for PAGER inventory development is at the country level except in the U.S., where California and the rest of the U.S. are treated as separate regions. In cases of countries where the inventory distribution is known only for certain geographic location instead of country as a whole, we have considered the same distribution to be valid for the entire country. Future inventory development for PAGER warrants much higher resolution beyond the existing country-level distribution in order to incorporate regional variations in the loss estimation (highly developed urban area of a country vs. remote, less developed area; seismically prone areas within a country or large-sized countries with high geological variation).

Scope of Inventory Updating

The inventory developed within the framework of the PAGER inventory requirements allows easy updating of country/region-specific inventory information based on the quality of inventory data and its vintage. The present investigation suggests that for many countries, the inventory information is extremely limited or nonexistent. However, we believe that future research studies or data compilation efforts would fill such gaps and would also help in improving the global inventory data compilation for the PAGER project. One such effort is envisioned through a joint collaborative project between USGS and EERI’s World Housing Encyclopedia (WHE). The WHE-PAGER project is an ongoing collaborative effort initiated by a group of experts from World Housing Encyclopedia (WHE) and U.S. Geological Survey’s PAGER project for better estimation of building inventory and building vulnerability worldwide (Porter, Greene and others, 2008). Note that the existing online WHE report database (EERI, 2007) covers only residential building types and does not cover information specific to (1) nonresidential building types, (2) fraction of building types in rural or urban areas, (3) vulnerability characteristics, and (4) occupancy characteristics (day and night occupancy pattern). The WHE-PAGER project provides a framework for compilation of this information in a simple and consistent format solicited mainly from earthquake engineering professionals from different countries. The data compiled in this exercise will also help in enhancing the housing stock distribution and vulnerability data for the existing WHE housing report for different countries.

Country-specific experts have been requested to provide their best estimate of the predominant building types in their country, the probability of collapse as a function of intensity for these building types, and the fraction of the urban and rural population who live and work in each building type. These estimates are only first-order approximations, and they are not meant to substitute for the more sophisticated modeling and analysis work that is taking place in some countries. Rather, the estimates provided here are meant to complement such efforts, and to be a first step in promoting the need for development of a rigorous database throughout the world. Similarly, the inventory-specific information compiled in the WHE-PAGER project provides a broad occupancy pattern of human exposure in urban, rural, residential or nonresidential dwellings by its construction types. It does not directly represent the fraction of dwellings by its construction types as obtained from other data sources during the housing inventory compilation effort of this report. However, PAGER casualty loss modeling efforts mainly require human exposure distribution by its construction types.

Housing type distribution by its construction material (given by most of the data sources such as Housing Censuses, UN-compilations or published reports) for a country is similar to human exposure distribution by construction types as long as average occupancy (number of people) per construction type does not change. It has been assumed that fraction of dwellings by construction types as compiled during this report is generally similar to fraction of population occupied by certain construction types as obtained in WHE-PAGER survey. The distribution of population exposure by time of day and by type of occupancy for a given density of population (urban or rural environment) as required for earthquake casualty loss modeling is discussed in detail by Jaiswal and Wald (work in progress).

Within short span, the WHE-PAGER survey resulted in a development of comprehensive inventory-specific information for 23 countries in a standardized format covering various aspects of human occupancy pattern, construction types and vulnerability for individual countries (*www.world*-housing.net). Table 21 shows a response obtained from expert from Japan which indicates various construction types common in Japan and the occupancy pattern associated with each construction type both in residential and nonresidential units. The growing responses of professionals especially from earthquake prone countries have clearly demonstrated the need of such an open knowledge-sharing environment, which can help not only to identify elements at risk but also to develop indigenous earthquake risk mitigation measures to minimize the consequences. This report includes the inventory-specific information solicited from country-specific expert during the first phase of WHE-PAGER inventory database and is provided in an electronic supplement (Appendix VII) of this report.

Summary

The framework proposed for PAGER inventory development in this investigation utilizes several nonproprietary and openly available global data sources and collates them using certain predefined criteria on quality and vintage and at the required geographic resolution (presently at country level, though each sub region/polygon within a particular country could be treated in the same way). This framework provides a globally consistent approach for treating a variety of diverse datasets obtained from sources with varying levels of uncertainty, quantity, and quality. The investigation results in synthesis of different data sources of residential housing types with variable quality to produce a single, consistent global inventory dataset for predicting social and economic impacts of global earthquakes.

Even though better quality building data exist for various countries, much of it is proprietary, being available to either insurance or re-insurance agencies, country-specific research institutions, or private industry. Often, such data are focused on insured (and likely engineered) properties and thus would not be useful for overall country-wide inventory and impact assessment. This investigation demonstrates that despite the substantial efforts that have been made over recent years by census agencies around the world, several limitations must be overcome before housing census survey data can be directly utilized for global earthquake loss estimation and mitigation. This report also points out that due to limited and poor quality of some of the datasets for certain hazard-prone countries which later were indicated by “Low” ratings, it is essential that we, collectively, identify suitable cost-effective options for compiling such information. The WHE-PAGER project demonstrates one such alternative for compiling an open, collaborative, peer-reviewed data for PAGER inventory development as well as other uses.

In the present investigation, we considered country-level aggregate distributions of housing units based on construction type for global earthquake casualty estimation. This approach was warranted by the general lack of data availability beyond this resolution globally. Nevertheless, once finer resolution data become available, the present framework can easily utilize them by creating additional subregions within a country to estimate appropriate building inventory classification. Likewise, results from our general approach stand as a framework and global default “starting model,” which, we readily concede, portions of which will be replaced with higher quality and higher resolution data as they become available.

The framework of present inventory development methodology is not entirely new and is in many ways analogous to the ATC-13 (ATC., 1985) and HAZUS (FEMA, 2006) inventory development methodologies. Here, we have adapted a similar approach for use on a global scale. Although this approach has already been available for more than 20 years, it has been utilized for recent inventory development procedures as in HAZUS. We used similar procedures, although we modified ours to suit our global inventory development requirements. In particular, we utilized a variety of data quality levels from a range of different types of data sources in self-consistent ways (in terms of vintage and quality ratings) before assigning inventory distribution for individual country. As the ratings and vintage information are available in the process of selecting the best data for a county, future updates could be easily made specific to particular source of data based on more recent information for that region or country. Even though the present framework is simple and easy to modify, it is largely untested, and it is therefore likely that future modifications may be required within the compiled database to improve the original data quality or to review specific data sources based on sampling and ground-truth observations.

Conclusions

The methodology described in this report provides a simple, cost-effective approach for global, country-wide, residential building inventory data compilation across various data sources with variable data quality and vintages. The main purpose of the inventory compilation is for earthquake loss assessment and risk management. The methodology consists of identification of data source, attribute mapping, quality assessment and rating, synthesis of data, and, where necessary, the assignment of inventory distribution to the countries with no data. The report identifies various key data sources that provide building inventory information at a global scale and develops a unique building attribute mapping scheme for each of the data sources to map the raw data into uniform PAGER structure types. The mapping scheme developed in the present report has been specifically designed with the expectation of future enhancements from new inventory data sources. For many countries, the building inventory and vulnerability data were clearly either completely missing, patchy, or could not be known during the phase of this investigation. However, development of country-pairing scheme to identify the “best neighbor” depending on data quality and vintage has helped in the development of reasonable default inventory distribution for such countries. Such a country pairing was based purely on expert judgment and will suffice until better quality data become available. An ongoing collaborative effort in the form of the WHE-PAGER project during its second phase will help to replace country-pairing based data synthesis and will result in better estimation of building inventory and building vulnerability worldwide. This report summarizes the procedure adopted for housing stock data development for more than 200 countries (fig. 17) and provides detailed discussion on inventory data development for a few example countries. Although the database development exercise was extremely laborious and time-consuming due to inherent limitations in the raw data, we have made a sincere effort to develop a building inventory distribution database for all the residential building stock at a global scale within a short span of 6 months, with extremely limited resources.

The report (along with its electronic supplement) also discusses the nature of available inventory data and its limitations, develops a framework of future inventory compilation using the source specific mapping scheme, and seeks various avenues for better inventory data compilations at global scale which can be utilized for PAGER and other loss estimation needs. Future inventory updating or adoption of more recent information (such as, satellite-based inventory data compilation, the availability of region-specific or more recent loss-centric inventory data especially covering financial aspects of losses) could easily replace the default estimation present in the database and enhance the overall quality of this global inventory data. Because the attribute mapping has been applied globally to all the data and is based on limited understanding in terms of regional construction practice and accessibility of published reports or research articles or Internet research, future updating will be required for many countries as specific information becomes available via the scientific community. This investigation also demonstrates that there is a strong need to seek an exercise which can encourages open data development and sharing mechanisms at global scale in order to continue improving the global building inventory data especially of nonresidential buildings and to seek various avenues for improving the raw inventory data compilation efforts at local levels by adopting globally consistent data formats that can be used for PAGER and other loss estimation needs.

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Glossary

Building Inventory Building stock distribution according to its structure types.

Construction/Structure Type An assembly of one or several units to create a space for living or shelter. A structure type is defined in general based on several factors, including structural material used in construction, horizontal and vertical load resisting system, or performance of structural system during earthquake ground shaking.

Dwelling A structure, part of a structure, or group of structures that is used, or intended to be used as a place where people reside. A dwelling may be permanent or temporary and may function as private or non-private. This term is commonly used in defining construction characteristics for Population and Housing Census surveys.

EERI Earthquake Engineering Research Institute

Household One person usually living alone, or two or more people usually living together and sharing facilities (such as, eating facilities, cooking facilities, bathroom and toilet facilities, a living area), in a private dwelling. This term is commonly used in conducting Population and Housing Census surveys.

PAGER Prompt Assessment of Global Earthquakes for Response

WHE World Housing Encyclopedia

Appendix I

PAGER structure type categories used for global building inventory development.

Label	Description (according to construction/structure type)	Average No. of stories	Typical
W	**WOOD**	**1-3**	**2**
W1	Wood Frame, Wood Stud, Wood, Stucco, or Brick Veneer	1-2	1
W2	Wood Frame, Heavy Members, Diagonals or Bamboo Lattice, Mud Infill	All	1
W3	Wood Frame, Prefabricated Steel Stud Panels, Wood or Stucco Exterior Walls	2-3	2
W4	Log building	1-2	1
S	**STEEL**	**All**	**1**
S1	Steel Moment Frame	All	1
S1L	Low-Rise	1-3	2
S1M	Mid-Rise	4-7	5
S1H	High-Rise	8+	13
S2	Steel Braced Frame	All	1
S2L	Low-Rise	1-3	2
S2M	Mid-Rise	4-7	5
S2H	High-Rise	8+	13
S3	Steel Light Frame	All	1
S4	Steel Frame with Cast-in-Place Concrete Shear Walls	All	1
S4L	Low-Rise	1-3	2
S4M	Mid-Rise	4-7	5
S4H	High-Rise	8+	13
S5	Steel Frame with Un-reinforced Masonry Infill Walls	All	1
S5L	Low-Rise	1-3	2
S5M	Mid-Rise	4-7	5
S5H	High-Rise	8+	13
C	**REINFORCED CONCRETE**	**All**	**1**
C1	Ductile Reinforced Concrete Moment Frame	All	1
C1L	Low-Rise	1-3	2
C1M	Mid-Rise	4-7	5
C1H	High-Rise	8+	13
C2	Reinforced Concrete Shear Walls	All	1

C2L	Low-Rise	1-3	2
C2M	Mid-Rise	4-7	5
C2H	High-Rise	8+	13
C3	Nonductile Reinforced Concrete Frame with Masonry Infill Walls	All	1
C3L	Low-Rise	1-3	2
C3M	Mid-Rise	4-7	5
C3H	High-Rise	8+	13
C4	Nonductile Reinforced Concrete Frame without Masonry Infill Walls	All	1
C4L	Low-Rise	1-3	2
C4M	Mid-Rise	4-7	5
C4H	High-Rise	8+	13
C5	Steel Reinforced Concrete (Steel Members Encased in Reinforced Concrete)	All	1
C5L	Low-Rise	1-3	2
C5M	Mid-Rise	4-7	5
C5H	High-Rise	8+	13
PC1	Precast Concrete Tilt-Up Walls	All	1
PC2	Precast Concrete Frames with Concrete Shear Walls	All	1
PC2L	Low-Rise	1-3	2
PC2M	Mid-Rise	4-7	5
PC2H	High-Rise	8+	13
RM	**REINFORCED MASONRY**	All	**1**
RM1	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	All	1
RM1L	Low-Rise	1-3	2
RM1M	Mid-Rise (4+ stories)	4-7	5
RM2	Reinforced Masonry Bearing Walls with Concrete Diaphragms	All	1
RM2L	Low-Rise	1-3	2
RM2M	Mid-Rise	4-7	5
RM2H	High-Rise	8+	13
MH	**Mobile Homes**	All	**1**
M	**MUD WALLS**	**1**	**1**
M1	Mud Walls without Horizontal Wood Elements	1-2	1
M2	Mud Walls with Horizontal Wood Elements	1-3	2
A	**ADOBE BLOCK (UNBAKED DRIED MUD BLOCK) WALLS**	**1-2**	**1**

A1	Adobe Block, Mud Mortar, Wood Roof and Floors	1-2	1
A2	Same as A1, Bamboo, Straw, and Thatch Roof	1-2	1
A3	Same as A1, Cement-Sand Mortar	1-3	2
A4	Same as A1, Reinforced Concrete Bond Beam, Cane and Mud Roof	1-3	2
A5	Same as A1, with Bamboo or Rope Reinforcement	1-2	1
RE	**RAMMED EARTH/PNEUMATICALLY IMPACTED STABILIZED EARTH**	**1-2**	**1**
RS	**RUBBLE STONE (FIELD STONE) MASONRY**	All	**1**
RS1	Local Field Stones Dry Stacked (No Mortar). Timber Floors. Timber, Earth, or Metal Roof.	1-2	1
RS2	Same as RS1 with Mud Mortar.	1-2	1
RS3	Same as RS1 with Lime Mortar.	1-3	2
RS4	Same as RS1 with Cement Mortar, Vaulted Brick Roof and Floors	1-3	2
RS5	Same as RS1 with Cement Mortar and Reinforced Concrete Bond Beam.	1-3	2
DS	**RECTANGULAR CUT STONE MASONRY BLOCK**	All	**1**
DS1	Rectangular Cut Stone Masonry Block with Mud Mortar, Timber Roof and Floors	1-2	1
DS2	Same as DS1 with Lime Mortar	1-3	2
DS3	Same as DS1 with Cement Mortar	1-3	2
DS4	Same as DS2 with Reinforced Concrete Floors and Roof	1-3	2
UFB	**UNREINFORCED FIRED BRICK MASONRY**	All	**1**
UFB1	Unreinforced Brick Masonry in Mud Mortar without Timber Posts	1-2	1
UFB2	Unreinforced Brick Masonry in Mud Mortar with Timber Posts	1-2	1
UFB3	Unreinforced Fired Brick Masonry, Cement Mortar, Timber Flooring, Timber or Steel Beams and Columns, Tie Courses (Bricks Aligned Perpendicular to the Plane of the Wall)	1-3	2
UFB4	Same as UFB3, but with Reinforced Concrete Floor and Roof Slabs	1-3	2
UCB	**UNREINFORCED CONCRETE BLOCK MASONRY, LIME/CEMENT MORTAR**	All	**1**
MS	**MASSIVE STONE MASONRY IN LIME/CEMENT MORTAR**	All	**1**
TU	**PRECAST CONCRETE TILT-UP WALLS** (same as HAZUS Type PC1 in Developing and Undeveloped Countries)	All	**1**
INF	**INFORMAL CONSTRUCTIONS** (parts of Slums/Squatters) Constructions Made of Wood/Plastic Sheets/Galvanized Iron sheets/Light Metal or Composite etc., not Confirming to Engineering Standards.	All	**1**
UNK	Unknown Category (Not specified)	All	**1**

Note: All-refers to all the possible ranges of number of stories of a particular structure type.

Appendix II

Average occupancy per dwelling type compiled from United Nations data (UNECE, 2006).

Serial No.	Country	Year	Total persons/housing unit		
			Total	Urban	Rural
1	Albania	2001	3.9	3.9*	3.9*
2	Algeria	2006	6.1	6.1*	6.1*
3	Argentina	1991	3.8	3.8	4.1
4	Austria	1997	2.5	2.3	3.1
5	Azerbaijan	1998	4.9	4.4	5.8
6	Bahamas	1990	4.1	4.2	3.6
7	Bangladesh	2006	5.9	5.9*	5.9*
8	Belgium	1991	2.5	2.5	2.8
9	Bermuda	1991	2.6	2.6	2.5
10	Brazil	1998	3.8	3.7	4.1
11	Bulgaria	1992	3.0	3.1	2.9
12	Burkina Faso	1991	6.6	6.4	6.6
13	Cambodia	2006	6.2	6.2*	6.2*
14	Canada	1996	2.6	2.6	3.2
15	Channel Islands Guernsey	1996	2.5	2.5*	2.5*
16	Columbia	1993	4.5	4.3	5.0
17	Congo-Brazzaville	2006	8.1	8.1*	8.1*
18	Costa Rica	1997	4.2	4.0	4.3
19	Croatia	1991	3.2	3.1	3.4
20	Cyprus	1992	3.2	3.2	3.3
21	Czech Republic	1991	2.8	2.7	2.9
22	Denmark	2003	2.1	2.1*	2.1*
23	Egypt	1996	4.6	4.3	5.0
24	Estonia	2003	2.2	2.2*	2.2*
25	Finland	1998	2.3	2.9	2.5
26	France	1990	2.6	2.5	2.8
27	French Polynesia	2006	5.8	5.8*	5.8*
28	Gabon	2006	6.3	6.3*	6.3*
29	Gambia	1993	8.9	7.0	10.5
30	Greece	2001	2.0	2.0*	2.0*
31	Guam	1990	4.0	3.7	4.1
32	Guatemala	1994	5.3	5.0	5.5
33	Guinea	2006	6.3	6.3*	6.3*
34	Guinea- Bissau	2006	5.6	5.6*	5.6*
35	Hong Kong	1996	3.5	3.5*	3.5*
36	Hungary	1990	2.7	2.7	2.9
37	Iceland	1993	2.7	2.7*	2.7*
38	Ireland	2002	2.8	2.8*	2.8*
39	Jordan	2006	5.7	5.7*	5.7*
40	Korea	1995	4.7	5.2	3.5
41	Kuwait	2006	6.4	6.4*	6.4*
42	Kyrgyzstan	2006	5.7	5.7*	5.7*
43	Latvia	2003	2.4	2.4*	2.4*
44	Lesotho	1996	5.0	5.0*	5.0*

45	Liechtenstein	2000	2.3	2.3*	2.3*
46	Luxembourg	2001	2.6	2.6*	2.6*
47	Macau	1996	3.5	3.5*	3.5*
48	Macedonia	2002	2.9	2.9*	2.9*
49	Malaysia	1991	4.9	4.5	5.3
50	Malta	1983	3.0	3.0*	3.0*
51	Mauritius	1990	4.9	4.5	5.1
52	Mexico	1995	4.7	4.5	5.1
53	Moldova	2002	2.8	2.8*	2.8*
54	Montenegro	2002	2.4	2.4*	2.4*
55	Netherlands	1998	2.3	2.2	2.5
56	Nicaragua	1995	5.8	5.5	6.1
57	Norway	1990	2.4	2.3	2.6
58	Pakistan	2006	7.2	7.2*	7.2*
59	Panama	1990	4.4	4.2	4.7
60	Pitcairn	1999	2.9*	2.9*	2.9
61	Poland	1995	3.5	3.2	4.1
62	Portugal	1991	3.2	3.1	3.3
63	Puerto Rico	1990	3.3	3.2	3.5
64	Republic of Moldova	2003	2.8	2.8*	2.8*
65	Romania	2003	2.7	2.7*	2.7*
66	Sabah	1991	5.5*	5.5	5.5*
67	Saudi Arabia	2006	5.9	5.9*	5.9*
68	Serbia	2002	2.5	2.5*	2.5*
69	Serbia and Montenegro	1999	3.3	3.3*	3.3*
70	Slovakia	1991	3.3	3.1	3.5
71	Slovenia	2003	2.5	2.5*	2.5*
72	St. Helena	1998	3.1	3.1*	3.1*
73	Sudan	2006	6.1	6.1*	6.1*
74	Sweden	1990	2.1	2.1	2.4
75	Switzerland	1990	2.4	2.3	2.6
76	Syrian Arab Republic	1994	6.7	6.3	7.1
77	Tonga	1996	6.0	6.1	6.0
78	Turkey	1994	4.4	4.2	4.7
79	United Arab Emirates	2006	6.4	6.4*	6.4*
80	United Kingdom	1996	2.4	2.4	2.5
81	United States	1997	2.6	2.6	2.7
82	Uruguay	1996	3.3	3.3	3.3
83	Uzbekistan	2006	5.8	5.8*	5.8*
84	Yugoslavia	1991	3.2	3.1	3.3

* interpreted data where specific estimates are unavailable.

Appendix III

Estimated work (labor) force population in different countries.

Serial No.	Country	Work (Labor) Force	Population	Fraction	Year
1	Afghanistan	15000000	31889923	47.0%	2007
2	Albania	1090000	3600523	30.3%	2007
3	Algeria	9310000	33333216	27.9%	2007
4	American Samoa	17630	57663	30.6%	2007
5	Andorra	42420	71822	59.1%	2007
6	Angola	6393000	12263596	52.1%	2007
7	Anguilla	6049	13677	44.2%	2007
8	Antigua and Barbuda	30000	69481	43.2%	2007
9	Argentina	15350000	40301927	38.1%	2007
10	Armenia	1200000	2971650	40.4%	2007
11	Aruba	41500	100018	41.5%	2007
12	Australia	10660000	20434176	52.2%	2007
13	Austria	3880000	8199783	47.3%	2007
14	Azerbaijan	5191000	8120247	63.9%	2007
15	Bahamas	176300	305655	57.7%	2007
16	Bahrain	352000	708573	49.7%	2007
17	Bangladesh	68000000	150448339	45.2%	2007
18	Barbados	128500	280946	45.7%	2007
19	Belarus	4300000	9724723	44.2%	2007
20	Belgium	4890000	10392226	47.1%	2007
21	Belize	113000	294385	38.4%	2007
22	Benin	3211000	8078314	39.7%	2007
23	Bermuda	38360	66163	58.0%	2007
24	Bolivia	4300000	9119152	47.2%	2007
25	Bosnia and Herzegovina	1026000	4552198	22.5%	2007
26	Botswana	288400	1815508	15.9%	2007
27	Brazil	96340000	190010647	50.7%	2007
28	Brunei Darussalam	180400	374577	48.2%	2007
29	Bulgaria	3510000	7322858	47.9%	2007
30	Burkina Faso	5000000	14326203	34.9%	2007
31	Burundi	2990000	8390505	35.6%	2007
32	Cambodia	7000000	13995904	50.0%	2007
33	Cameroon	6394000	18060382	35.4%	2007
34	Canada	17590000	33390141	52.7%	2007
35	Cape Verde	120600	423613	28.5%	2007
36	Cayman Islands	23450	46600	50.3%	2007
37	Chad	2719000	9885661	27.5%	2007
38	Chile	6940000	16284741	42.6%	2007
39	China	798000000	1321851888	60.4%	2007

40	Colombia	20810000	44379598	46.9%	2007
41	Comoros	144500	711417	20.3%	2007
42	Congo	15000000	65751512	22.8%	2007
43	Cook Islands	6820	21750	31.4%	2007
44	Costa Rica	1866000	4133884	45.1%	2007
45	Côte d'ivoire	6738000	18013409	37.4%	2007
46	Croatia	1720000	4493312	38.3%	2007
47	Cuba	4820000	11394043	42.3%	2007
48	Cyprus	371000	773000	48.0%	2006
49	Czech Republic	5310000	10228744	51.9%	2007
50	Denmark	2910000	5468120	53.2%	2007
51	Djibouti	282000	496374	56.8%	2007
52	Dominica	25000	72386	34.5%	2007
53	Dominican Republic	3896000	9365818	41.6%	2007
54	Ecuador	4570000	13755680	33.2%	2007
55	Egypt	21800000	80335036	27.1%	2007
56	El Salvador	2856000	6948073	41.1%	2007
57	Estonia	673000	1315912	51.1%	2007
58	Ethiopia	27270000	76511887	35.6%	2007
59	Falkland Islands (Malvinas)	1724	3105	55.5%	2007
60	Faroe Islands	24250	47511	51.0%	2007
61	Federated States of Micronesia	37410	107862	34.7%	2007
62	Fiji	137000	918675	14.9%	2007
63	Finland	2620000	5238460	50.0%	2007
64	France	27880000	63713926	43.8%	2007
65	French Polynesia	65930	278963	23.6%	2007
66	Gabon	581000	1454867	39.9%	2007
67	Gambia	400000	1688359	23.7%	2007
68	Gaza Strip	259000	1482405	17.5%	2007
69	Georgia	2040000	4646003	43.9%	2007
70	Germany	43660000	82400996	53.0%	2007
71	Ghana	10870000	22931299	47.4%	2007
72	Gibraltar	12690	27967	45.4%	2007
73	Greece	4880000	10706290	45.6%	2007
74	Greenland	32120	56344	57.0%	2007
75	Grenada	42300	89971	47.0%	2007
76	Guam	62050	173456	35.8%	2007
77	Guatemala	5020000	12728111	39.4%	2007
78	Guernsey	31470	65573	48.0%	2007
79	Guinea	3700000	9947814	37.2%	2007
80	Guinea-Bissau	480000	1472780	32.6%	2007
81	Guyana	418000	769095	54.3%	2007
82	Haiti	3600000	8706497	41.3%	2007
83	Honduras	2589000	7483763	34.6%	2007
84	Hong Kong	3630000	6980412	52.0%	2007
85	Hungary	4200000	9956108	42.2%	2007
86	Iceland	173000	301931	57.3%	2007

87	India	509300000	1129866154	45.1%	2007
88	Indonesia	108200000	234693997	46.1%	2007
89	Iran, Islamic Republic of	24360000	65397521	37.2%	2007
90	Iraq	7400000	27499638	26.9%	2007
91	Ireland	2120000	4109086	51.6%	2007
92	Isle of Man	39690	75831	52.3%	2007
93	Israel	2600000	6426679	40.5%	2007
94	Italy	24630000	58147733	42.4%	2007
95	Jamaica	1100000	2780132	39.6%	2007
96	Japan	66440000	127433494	52.1%	2007
97	Jersey	53560	91321	58.7%	2007
98	Kazakhstan	7834000	15284929	51.3%	2007
99	Kenya	1955000	36913721	5.3%	2007
100	Kiribati	7870	107817	7.3%	2007
101	Korea, Democratic People's Republic of	9600000	23301725	41.2%	2007
102	Korea, Republic of	23770000	49044790	48.5%	2007
103	Kuwait	1136000	2505559	45.3%	2007
104	Kyrgyzstan	2700000	5284149	51.1%	2007
105	Lao People's Democratic Republic	2100000	6521998	32.2%	2007
106	Latvia	1136000	2259810	50.3%	2007
107	Lebanon	1500000	3925502	38.2%	2007
108	Lesotho	838000	2125262	39.4%	2007
109	Libyan Arab Jamahiriya	1787000	6036914	29.6%	2007
110	Liechtenstein	29500	34247	86.1%	2007
111	Lithuania	1617000	3575439	45.2%	2007
112	Luxembourg	203000	480222	42.3%	2007
113	Macau	248000	456989	54.3%	2007
114	Macedonia, the former Yugoslav Republic of	899000	2055915	43.7%	2007
115	Madagascar	7300000	19448815	37.5%	2007
116	Malawi	4500000	13603181	33.1%	2007
117	Malaysia	10730000	24821286	43.2%	2007
118	Maldives	101300	369031	27.5%	2007
119	Mali	3930000	11995402	32.8%	2007
120	Malta	164000	401880	40.8%	2007
121	Marshall Islands	14680	61815	23.7%	2007
122	Mauritania	786000	3270065	24.0%	2007
123	Mauritius	555000	1250882	44.4%	2007
124	Mayotte	44560	208783	21.3%	2007
125	Mexico	38090000	108700891	35.0%	2007
126	Moldova, Republic of	1339000	4320490	31.0%	2007
127	Mongolia	1577000	2951786	53.4%	2007
128	Montenegro	144000	623000	23.1%	2005
129	Morocco	11250000	33757175	33.3%	2007
130	Mozambique	9400000	20905585	45.0%	2007
131	Myanmar	28490000	47373958	60.1%	2007
132	Namibia	653000	2055080	31.8%	2007

133	Nepal	11110000	28901790	38.4%	2007
134	Netherlands	7600000	16570613	45.9%	2007
135	Netherlands Antilles	83600	223652	37.4%	2007
136	New Caledonia	78990	221943	35.6%	2007
137	New Zealand	2180000	4115771	53.0%	2007
138	Nicaragua	2261000	5675356	39.8%	2007
139	Niger	70000	12894865	0.5%	2007
140	Nigeria	48990000	135031164	36.3%	2007
141	Northern Mariana Islands	44470	84546	52.6%	2007
142	Norway	2420000	4627926	52.3%	2007
143	Oman	920000	3204897	28.7%	2007
144	Pakistan	48290000	164741924	29.3%	2007
145	Palau	9777	20842	46.9%	2007
146	Panama	1441000	3242173	44.4%	2007
147	Papua New Guinea	3477000	5795887	60.0%	2007
148	Paraguay	2742000	6669086	41.1%	2007
149	Peru	9210000	28674757	32.1%	2007
150	Philippines	35790000	91077287	39.3%	2007
151	Pitcairn	15	48	31.3%	2007
152	Poland	17260000	38518241	44.8%	2007
153	Portugal	5580000	10642836	52.4%	2007
154	Puerto Rico	1300000	3944259	33.0%	2007
155	Qatar	508000	907229	56.0%	2007
156	Romania	9330000	22276056	41.9%	2007
157	Russian Federation	73880000	141377752	52.3%	2007
158	Rwanda	4600000	9907509	46.4%	2007
159	Saint Helena	2486	7543	33.0%	2007
160	Saint Kitts and Nevis	18170	39349	46.2%	2007
161	Saint Lucia	43800	170649	25.7%	2007
162	Saint Pierre and Miquelon	3450	7036	49.0%	2007
163	Saint Vincent and the Grenadines	41680	118149	35.3%	2007
164	Samoa	90000	214265	42.0%	2007
165	San Marino	20470	29615	69.1%	2007
166	Sao Tome and Principe	35050	199579	17.6%	2007
167	Saudi Arabia	7125000	27601038	25.8%	2007
168	Senegal	4749000	12521851	37.9%	2007
169	Serbia	2069000	7441000	27.8%	2005
170	Seychelles	30900	81895	37.7%	2007
171	Sierra Leone	1369000	6144562	22.3%	2007
172	Singapore	2400000	4553009	52.7%	2007
173	Slovakia	2629000	5447502	48.3%	2007
174	Slovenia	1026000	2009245	51.1%	2007
175	Solomon Islands	249200	566842	44.0%	2007
176	Somalia	3700000	9118773	40.6%	2007
177	South Africa	16090000	43997828	36.6%	2007
178	Spain	21770000	40448191	53.8%	2007
179	Sri Lanka	7500000	20926315	35.8%	2007

180	Sudan	7415000	39379358	18.8%	2007
181	Suriname	156700	470784	33.3%	2007
182	Swaziland	300000	1133066	26.5%	2007
183	Sweden	4590000	9031088	50.8%	2007
184	Switzerland	3810000	7554661	50.4%	2007
185	Syrian Arab Republic	5505000	19314747	28.5%	2007
186	Taiwan, Province of China	10460000	22858872	45.8%	2007
187	Tajikistan	3700000	7076598	52.3%	2007
188	Tanzania, United Republic of	19350000	39384223	49.1%	2007
189	Thailand	36410000	65068149	56.0%	2007
190	Togo	1302000	5701579	22.8%	2007
191	Tonga	33910	116921	29.0%	2007
192	Trinidad and Tobago	618000	1056608	58.5%	2007
193	Tunisia	3502000	10276158	34.1%	2007
194	Turkey	24800000	71158647	34.9%	2007
195	Turkmenistan	2320000	5097028	45.5%	2007
196	Turks and Caicos Islands	4848	21746	22.3%	2007
197	Uganda	13760000	30262610	45.5%	2007
198	Ukraine	22300000	46299862	48.2%	2007
199	United Arab Emirates	2968000	4444011	66.8%	2007
200	United Kingdom	31100000	60776238	51.2%	2007
201	United States	151400000	301139947	50.3%	2007
202	Uruguay	1270000	3460607	36.7%	2007
203	Uzbekistan	14440000	27780059	52.0%	2007
204	Vanuatu	76410	211971	36.0%	2007
205	Venezuela	12500000	26023528	48.0%	2007
206	Viet Nam	44580000	85262356	52.3%	2007
207	Virgin Islands, British	12770	23552	54.2%	2007
208	Virgin Islands, U.S.	43980	108448	40.6%	2007
209	Wallis and Futuna	3104	16309	19.0%	2007
210	West Bank	568000	2535927	22.4%	2007
211	Western Sahara	12000	382617	3.1%	2007
212	Yemen	5759000	22230531	25.9%	2007
213	Zambia	4903000	11477447	42.7%	2007
214	Zimbabwe	3958000	12311143	32.1%	2007
215	California (treated as a separate region than the rest of United States)	17688900	36457549	48.5%	2006

Appendix IV

Attribute mapping developed for different databases.

United Nations Compilation, 1993

We performed mapping of the construction material nomenclature used in the UN (1993) database to equivalent PAGER structure types shown in below. For example, housing units with brick and mud as a construction material of external walls have been mapped with “Unreinforced fire brick masonry with mud mortar” or UFB1 structure type. Similarly, housing units made of the Stone/Concrete category have been assumed to be made of load-bearing walls of stone masonry and concrete roof and are mapped to “Field Stone masonry with cement mortar and reinforced concrete bond beam” which supports the concrete or other roof sheeting. Though for most common types and in case of large number of countries, the mapping seemed to be acceptable and simple, for typical cases such as reinforced concrete buildings with infill brick or concrete block masonry construction, it was likely that the existing database classifies them as belonging to either brick or to concrete block construction, whereas, in reality, the structural system is made of reinforced concrete beams-column elements. Under these circumstances, we used expert opinion supported with Internet research for understanding the most common construction types in that country to assign them to the appropriate structure type. Future research and (or) data compiled from rigorous field investigation by professional engineers could help better assess the distribution of such housing units and to reclassify them.

According the database, 31 percent of occupied housing units in case of the Dominican Republic have been constructed using ”concrete” as an external wall material. Since no specific information about its structural system is available in the original data, it was extremely difficult to distribute this stock in several concrete structure type categories based on limited country-specific research; hence we have categorized this building stock as general concrete (C) structure type. The objective was to involve minimum interference with basic information about fraction available from a raw data source. It is worth noting that other databases, such as WHE-PAGER expert opinion survey, recent housing census or published literature will supersede this particular database (which is old and has “Low” quality assigned) in later phases of inventory development. However, in the absence of any other information for this country, these data will remain part of PAGER inventory with lowest confidence until more recent updating can be made based on further research.

In general, it has been found that reinforced concrete moment frame with infill masonry construction is common in rapidly developing countries and are limited to urban areas and forms very small fraction of total housing types in a country. It is important to note that the existing UN 1993 database has certain limitations and is classified with “Low” in the PAGER rating category database as described in the previous section. Hence the processed database should be used within its limitations.

Sr. No.	UN (1993) Descriptions (Construction of Wall)	PAGER Structure Type
1	Adobe; Adobe and mud; Adobe and wood	A
2	Concrete; Concrete/Bricks	C
3	Cement	C3
4	Iron cement skeleton	C5
5	Stone/Cement	DS3
6	Fibro-asbestos; Local material; Makeshift or improvised material; Metal sheets; Metal/Asbestos; Poles; Poles/mud; Pre-fabricated; Quirintin; Quirintin/mud; Re-used material; Traditional bure material; Zinc	INF
7	Clay; Cob; Mud; Mud and Concrete; Mud brick; Mud brick/blocks	M
8	Wood and Mud	M2
9	Stone; Wood and Stone	RS
10	Rock Sheet	RS1
11	Stone/Clay	RS2
12	Stone/Concrete	RS5
13	Blockets and Cement; Blocks; Blocks and bricks; Brick/stone; Cement block; Cement/brick; Concrete blocks; Stone/block	UCB
14	Baked/burned brick; Brick; Brick and wood; Brick, stone; Brick, Wooden beam; Masonry	UFB
15	Stone and mud; Stone/mud	UFB1
16	Brick and cement; Brick, Iron beam; Brick/concrete; Stone and cement	UFB3
17	All wood; Bamboo; Bamboo and thatch; Bamboo, palm; Bush; Cane; Cane/woodsticks; Cardboard plates; Cement/wood with iron roof; Palm; Palm planks; Palm/lattice; Panel; Permanent tin or Corrugated iron; Planks; Seasoned timber; Solid wood; Straw/Bamboo; Stucco; Thatch; Timber; Unseasoned timber; Waste Material; Wattle and Daub walls; Weaved straw; Wood; Wood and Bamboo; Wood and thatch; Wood wall and thatch roof; Wood, straw; Wood/Zinc	W
18	Wood and cement; Wood/Brick; Wood/Concrete; Wood/Iron	W1
19	Not stated; Other;	UNK

UN-HABITAT Compilation, 2007

Unlike the UN 1993 database, which has very limited description of construction material of external walls, UN 2007 database had quite a number of descriptions and it was quite time consuming to do the mapping of these descriptions with standard PAGER construction types. Table 2 shows typical raw data on housing units by construction material for Tanzania in the year 2004. It is interesting to note that 51 percent of housing units in this country have external walls made of cement bricks, which can be similar to unreinforced concrete block masonry construction or PAGER (UCB) type.

We have developed a new mapping scheme similar to the mapping scheme of the UN 1993 database using descriptions provided in the UN 2007 database. We used engineering judgment along with general Internet research and other published articles for specific cases to assign appropriate PAGER structure type against each wall material description as shown in below. For example Quincha type dwellings, common in Peru (http://en.wikipedia.org/wiki/Quincha), consist of light wooden frames infilled with interwoven cane and coated with a mixture of mud and plaster on both sides (Blondet, Torrealva and others, 2002). Such construction results in a very light and flexible structure and is remarkably good for heat insulation. In Peru, ancestral building methods such as adobe, tapial, and quincha take advantage of the local resources for housing construction. These construction methods have been used for centuries. Two-story houses were usually built with adobe first story and a lighter second story made out of Quincha. We classify such construction type into PAGER M2 category, as the primary construction material is wood and mud and the overall assembly of light wooden frame with mud is not designed to resist earthquake ground shaking. Another example includes sillar which is a consolidated volcanic ash generally used in the form of sillar blocks in traditional masonry constructions. We classified them into PAGER DS3 category.

Sr. No.	**UN-HABITAT (2007) Descriptions (Construction of Wall)**	**PAGER Structure Type**
1	Adobe; Adobe (mud bricks); Adobe-o-tapia; Adobe or "taquezal"; Adobe with sod; Brique en terre non cuite; Covered adobe; Earthen Bricks; Sundried bricks; Unbaked bricks; Unburnt bricks; Uncovered adobe	A
2	Cement	C3
3	Brique cuite; Stone blocks	DS
4	Piedra o sillar con cal o cemento	DS3
5	3-Banco; 4-Semi-dur; Blank Field (No description); Carton; Disposable material; Grass; Half solid; Hard; No walls; Other finished; Plastic/Cardboard; Plastic/Carton/Used metal sheet; Prefab; Prefab material; Semihard/semifinished/other; Tin; Tole; Tripley; Waste material; Without walls; Zinc, canvas, plastics	INF
6	Cob/daub/mud/clay; Compact dirt/mud; Dung; Earth; Earth, sand; Mud; Mud and Cement; Mud stones; Mud unpolished; Mud walls; Other dung materials; Tabique / Chinche	M
7	Terre battue	M1
8	Mud and pole; Poles and mud; Quincha (cañas con barro)	M2
9	Natural stone; Plaster/Finished; Rocks; Stone	RS
10	Piedra con barro; Stone with mud	RS2
11	Stone with lime / cement; Stone with lime / cement	RS3
12	Stone with cement	RS4
13	Block of cement; Blocks / bricks; Breeze blocks/parpens/stones/cement; Cement / Concrete blocks; Cement blocks; Cement bricks; Ciment/aglo/parpaing; Cinder blocks; Ladrillo o bloque de cemento	UCB
14	Alvenaria (finished); Baked bricks; Bare Brick/Cement Block; Bricks; Bricks/polished wood/premanufactured material; Finished bricks; Mixed brick	UFB
15	Burnt bricks with mud	UFB1
16	Baked bricks, cement; Brick/cement; Burnt bricks with cement	UFB3
17	Bamboo; Bamboo, planks; Bamboo, straw, other plants; Bark/straw/branch/bamboo; Bois/planches; Cane / trunks / bamboo / reed; Cane, palmtree, trunks; Corrugated iron 2-Toles; Corrugated iron sheet; Corrugated Iron/Zinc; Estera; Madera; Metalic sheet; Palm branches; Palm leaves; Palm tree; Palm tree "Yagua"; Palm, straw; Planks; Plywood; Polished wood; Raw wood; Straw, cane or palm; Straw/palm/bamboo/wood; Thatched; Timber; Wood; Wood /bamboo; Wood and grass; Wood planks; Wood planks / shingles; Wood poles; Wood/branches;	W
18	Ceramic tiles; Plycem or Nicalit tiles; Shingle "Tejamanil"; Wood / Concrete	W1
19	Bamboo / wood; Bamboo with mud plaster; Jute/Bamboo/mud (katcha)	W2
20	Others, Not specified, Unknown	UNK

Housing Census

The following table provides the classification of terms used in the description of housing units by construction material into PAGER structure type. The classification is similar to the procedure adopted for compilation of data from the UN database as explained in the previous section.

Sr. No.	Description (Construction of Wall)	PAGER Structure Type
1	Mud, Unburnt Brick; Un-baked bricks/Earth Bound; Adobe	A
2	Reinforced Concrete Construction (RCC); Concrete; Concrete/ brick/ stone	C
3	Fibro/asbestos cement; Others; Grass, thatch, Bamboo; Plastic, Polythene; Galvanized Iron (GI), Metal, Asbestos sheet; Galvanized iron/ aluminum; Asbestos; Glass; Makeshift/ salvaged/ improvised materials; Others/not reported; No walls; Mainly permanent materials; Non-permanent materials; Other Materials; Informal; Reused materials;	INF
4	Stone	RS
5	Steel-framed	S
6	Baked Bricks/Blocks/Stone; Block, Brick or Stone; Block	UCB
7	Double brick; Burnt brick; Brick	UFB
8	Mud Bonded Bricks/Stone	UFB1
9	Cement Bonded Bricks/Stones and Concrete; Cement or brick	UFB3
10	Wooden; Wood; Timber; Wood/Bamboo; Bamboo/ sawali/ cogon/ nipa; Wood/Branches; Wood and cement or brick; Wood	W
11	Brick veneer	W1
12	Wooden and fire-proofed; Half concrete/ brick/ stone and half wood	W2
13	Unknown; Other	UNK

World Housing Encyclopedia

The performance of building types during adverse ground shaking is characterized by its capacity to resist lateral forces caused immediately after an earthquake. Structural engineers responsible for designing earthquake resistant buildings, try to provide sufficient capacity within the structural system through arrangements of beam-columns, shear walls, reinforced masonry walls etc., to create adequate ductile lateral load resisting system. In most of the non-engineered buildings, the load-bearing walls (masonry walls made from brick, stone, or other material) or wood frames provide lateral load resistant system. Ideally, each construction type should be identified by its lateral load resisting system; however, such data are expensive to gather and it also requires involvement of engineering professionals. At the global level, it is extremely difficult to survey each individual building and compile data of fraction of various construction types within a certain geographic region to develop a global building inventory database. At regional levels, such exercises have been carried out based on engineering characterization of construction types; however, it has proved extremely time consuming and expensive even for very small geographic regions (portion of metropolitan area, city or suburb) (Faccioli, Pessina and others, 1999; Bommer, Spence and others, 2002; Erdik and Fahjan, 2006). Most of the housing surveys conducted around the world compile data based on predominant material used in the construction of building components such as wall, roof or floor. The mapping scheme on wall construction material to identify construction types has been used and the WHE housing types have been assigned with PAGER structure type, as shown in Appendix V.

Appendix V

Compilation of the Earthquake Engineering Research Institute's (EERI, 2007) World Housing Encyclopedia (WHE) database.

Name of Country	Name of Housing Type	PAGER Structure Category	No. of Stories	No. of Units	Occupancy (family per unit)	Work hours	Night hours	Rural /Urban	Inventory Description
Germany	Prefabricated metal construction of the Modern Movement	**S5L**	2-4	24	3-5 person per unit	Other	Other	Suburban	Some 300000 residential
Greece	Multistory reinforced concrete frame building	**C2M**	4-6	16	1	5 - 10	> 20	Urban	30 percent of entire housing stock
Greece	Load-bearing stone masonry building	**RS4**	2-4	1	1-2	< 5	5 - 10	Both	10 percent of entire housing stock
Greece	Reinforced concrete frame building with an independent vertical extension	**C3L**	2-4	2-3	2-3	< 5	5 - 10	Both	Common in the country
Italy	Single-family stone masonry house	**DS1**	2-4	2	1-2	< 5	5 - 10	Urban	Throughout Italy
Italy	Single-family historic brick masonry house (Casa unifamiliare in centro storico, Centro Italia)	**UFB3**	2-4	1	1	< 5	< 5	Urban	Throughout Centre Italy
Italy	Reinforced concrete frame building	**C3M**	4-10	10-30	1	> 20	> 20	Urban	Throughout urban area and common in Potenza
Italy	Brick masonry farmhouse with a "dead door".	**UFB3**	2-4	1	1	5 - 10	5 - 10	Rural	20 percent of entire housing stock
Italy	"Casa Torre" construction: multistory tower masonry with stone pillars and wood or arched beams	**MS**	4-7	1	1	5 - 10	5 - 10	Urban	Common in the country
Italy	Unreinforced stone wall housing (upper income)	**RS2**	4-6	1	1	< 5	< 5	Both	60 percent of housing stock of Umbria
Italy	Unreinforced stone wall rural housing (lower and middle income)	**RS2**	4	1-2	1-2	< 5	5 - 10	Rural	60 percent of rural building stock of Umbria
Portugal	Historic, braced frame timber buildings with masonry infill ('Pombalino' buildings)	**W2**	4-5	6-8	1	> 20	> 20 (5-10 for nonresidential)	Urban	Part of old building stock and common in Lisbon and other urban areas of Portugal
Romania	Reinforced concrete frame structure with diagonal bracings and brick infill walls	**C1M**	5-8	20	1	Other	Other	Urban	Few buildings especially in Bucharest
Romania	Reinforced concrete cast-in situ shear wall buildings ("OD"-type,	**C2H**	10-11	20-100	1	Other	Other	Urban	About 60 percent of new housing stock in Romania

	with "fagure" plan)								
Romania	Precast concrete panel apartment buildings	**PC1**	4-11	150	1	> 20	> 20	Urban	Common in all major urban areas
Romania	A single-family, two-story house with brick walls and timber floors	**UFB2**	2-4	1	1	< 5	< 5	Both	Common in rural and semi-urban areas. Construction practice is discontinued since 1940s
Romania	One family one-story house, also called "wagon house"	**UFB3**	1	1	1	< 5	< 5	Urban	Most common in small towns and urban areas
Romania	Block of flats with 11 floors out of cast-in-situ concrete, gliding frameworks	**C2H**	11-20	44	1	> 20	> 20	Urban	Typical distribution of building stock in Jassy in Romania-36 percent RC shear walls (this type), 36 percent large panels, 15 percent load bearing masonry, 13 percent current and lamellar frames
Romania	Early reinforced concrete frame condominium building with masonry infill walls designed for gravity loads only	**C3M**	5-10	25 (variable)	1	Other	Other	Urban	According to Lungu, Aldea and others (2000), Bucharest city has about 750000 housing in about 100000 buildings, from which 95000 are low rise (1-2 stories) and the rest in a 2/3 ratio high and midrise
Romania	Medium/high rise moment resisting reinforced concrete frame buildings.	**C3H**	4-18	30	1	> 20	> 20	Urban	About 90 percent of housing stock in Romania was built after 1950 and about 4 percent was built using RC constructions
Russian Federation	Small concrete block masonry walls with concrete floors and roofs	**UCB**	2-4	12 - 36	1	10 - 20	>20	Both	15 to 30 percent of housing stock in seismically prone areas of Russia
Russian Federation	Large concrete block walls with reinforced concrete floors and roof (typical series: 1-306c, 1-307c, 114c)	**UCB**	2-4	12 - 64 (48)	1	>20	Other	Both	15 to 30 percent of housing stock in seismically prone areas of Russia
Russian Federation	Large reinforced concrete panel buildings (Series 122, 135 and 1-464c)	**PC**	4-9	80	1	>20	Other	Urban	20 to 100 percent of housing stock in seismic zones of Russia and Central Asia
Russian Federation	Timber log building	**W4**	1	2-4	1	5 - 10	10 - 20	Rural	5 to 100 percent of housing stock for seismically prone areas mostly forest areas
Russian Federation	Wood panel wall buildings (typical seria 181-115-77 cm of "Giprolesprom")	**W1**	1	2	1	< 5	5 - 10	Rural	5 to 100 percent of housing stock for seismically prone areas mostly forest areas
Russian Federation	Buildings protected with "disengaging reserve elements"	**C1M**	5-10	60 (32-64)	1	> 20	> 20	Urban	Very small fraction (about 140 bldgs in one city)
Serbia and Montenegro	Precast, prestressed concrete frame structure with concrete shear walls	**PC2M**	5-10	40-200 (100)	1	> 20	> 20	Urban	Throughout Yugoslavia (over 50 percent in New Belgrade city), common in other cities
Serbia and	Confined masonry building with	**RM2L**	2-4	20 (1 - 50	1	> 20 (5-20)	> 20	Both	Widespread in both urban and

Montenegro	concrete floor slabs			)					rural areas of Yugoslavia
Slovenia	Rubble-stone masonry house	**RS3**	2-3	1 or 2	1	< 5	< 5	Both	About 24 percent of building stock in Upper Posocje
Slovenia	Unreinforced brick masonry apartment building	**UFB3**	4-6	12-60 (4-10 per floor)	1	> 20	> 20	Urban	30 percent entire housing stock in Slovenia
Slovenia	Confined brick masonry house	**RM2L**	1-2	1 - 2	1 or 2	< 5	5 - 10	Both	40 percent of housing stock in Slovenia
Switzerland	Fachwerkhaus in Dreiländereck (Half-timbered house in the "border triangle")	**W2**	1	1	1 or 2	< 5	5 - 10	Both	Common in the country
Switzerland	Urban residential buildings of the 19th century in the city of Basel	**UFB3 or MS**	4-5	4 - 5	1	5 - 10	10 - 20	Urban	Common in the country
Turkey	Reinforced concrete frame building with masonry infills	**C3M**	3-7	12	1	10 - 20	> 20	Urban	Approx. 80 percent of urban households in Turkey (about 50 percent of building stock in Istanbul, Izmir and Ankara with 75 percent with more than 3 stories)
Turkey	Tunnel form building	**C2H**	10-15	40-50	1	> 20	> 20	Urban and Suburban	Most common in densely populated urban and suburban areas
Algeria	Single-family reinforced concrete frame houses	**C3L**	1-3	1	1	< 5	5 - 10	Suburban	60-70 percent of housing stock in North Algeria which has highest seismic risk
Algeria	Stone masonry apartment building	**MS**	5-10	10-15	1	10 - 20	> 20	Urban	About 40 to 50 percent of total urban housing stock
Malawi	Rammed earth house with pitched roof (Nyumba yo dinda OR Nyumba ya mdindo)	**RE**	1	1	1	< 5	5 - 10	Rural	About 35 percent of total housing stock in Malawi
Malawi	Rural mud wall building (nyumba yo mata OR ndiwula)	**A2**	1	1	1	< 5	5 - 10	Rural	About 5 percent of entire stock of houses
Malawi	Unburnt brick wall building with pitched roof (nyumba ya zidina)	**UFB1**	1	1	1	< 5	5 - 10	Both	About 45 percent of total housing stock in Malawi
Canada	Single-family wood frame house	**W1**	1	1	1	< 5	5 - 10	Both	About 50 percent of building stock in British Columbia
Canada	Concrete shear wall highrise buildings	**C2H**	12-35	100-200	1	300	500	Urban	Commercial Business District (CBD) of cities in Canada
Mexico	Reinforced concrete multistory buildings	**C1H**	10-25	30	1	10	> 50	Urban	RC buildings account for 80 percent of building stock in Mexico
United States of America	Wood frame single family house	**W1**	1	1	1 or 2	< 5	5 - 10	Both	Western U.S.A., about 98 percent of housing stock
United States of America	Reinforced Concrete Moment Frame Building without Seismic Details	**C3**	4-15	20-70	1	> 20	> 20	Urban	Common in the country
El Salvador	Vivienda de Adobe (Adobe house)	**A2**	1	1	1	< 5	5 - 10	Both	Widespread in both urban and rural areas except San Salvador

Argentina	Confined block masonry house	**UCB**	1-2	1	1	< 5	< 5	Urban	Few cities e.g. San Juan
Argentina	Solid brick masonry house with composite hollow clay tile and concrete joist roof slabs	**UFB4**	1	1	1	5 - 10	5 - 10	Urban	About 30 to 70 percent in San Juan
Argentina	Traditional adobe house with reinforcement	**A4**	1	1	1	5 - 10	5 - 10	Rural	Few cities isolated construction
Argentina	Traditional adobe house without seismic features	**A1**	1	1	1	5 - 10	5 - 10	Rural	About 40 percent of construction type in Tulum valley where 85 percent of population of whole province
Chile	Buildings with hybrid masonry walls	**UCB**	2-4	8	1 or 2	5 - 10	> 20	Urban	Throughout Chile
Chile	Concrete frame and shear wall building	**C2H**	10-30	Non-Residential	Not applicable	> 20	5 - 10	Urban	About 15-20 percent of high rise (more than 10 story) building stock in Chile
Chile	Concrete shear wall buildings	**C2**	4-30	70 (4 - 10 per floor)	1	> 20	> 20	Urban	Mainly in large cities
Chile	Confined block masonry building	**UCB**	2-4	8	1 or 2	5 - 10	> 20	Both	Throughout Chile
Chile	Reinforced clay/concrete block masonry building	**RM2L**	1-3	8	1 or 2	10 - 20	> 20	Both	Throughout Chile
Chile	Steel frame buildings with shear walls	**S4**	3-24	80	1	> 20	> 20	Urban	Less than 2 percent and mainly in large cities
Colombia	Clay brick/concrete block masonry walls with concrete floors (predating seismic codes or with a few seismic features)	**UCB**	5	5	1	5 - 10	> 20	Urban	About 50 percent of housing stock of mid rise buildings (4 to 6 stories)
Colombia	Concrete Shear Wall Buildings	**C2H**	7-20	40	1	> 20	Other	Urban	About 2 to 3 percent of housing stock in cities
Colombia	Gravity concrete frame buildings (predating seismic codes)	**C3M**	5	5	1	5 - 10	> 20	Urban	About 60 percent of urban housing stock
Colombia	Non-engineered unreinforced brick masonry building	**UFB3 or UFB4**	2-4	3	1	< 5	5 - 10	Both	About 60 percent of housing stock in selected provinces
Peru	Adobe house	**A1**	1	1	1 or 2	< 5	5 - 10	Both	Common in the country
Peru	Confined masonry building	**RM2M**	4-6	6	1 or 2	10 - 20	> 20	Urban	Throughout Peru
Peru	Confined masonry house	**RM2L**	2-3	1	1	< 5	5 - 10	Both	Throughout Peru
Venezuela	Popular, non-engineered urban housing on flat terrain	**C3L**	2-3	2	1 or 2	< 5	10 - 20	Urban	About 40 percent of housing stock in Venezuela
Bangladesh	Single-story brick masonry house (EMSB1)	**UFB3**	1	1	1	< 5	5 - 10	Both	Throughout Bangladesh
China	Multistory base-isolated brick masonry building with reinforced concrete floors and roof	**C1H (Base Isolated)**	6 (5-10)	32	1	> 20	Other	Urban	Urban areas of China
Cyprus	Gravity designed reinforced concrete frame buildings with unreinforced masonry infill walls.	**C3M**	3-5	8 - 14	1	5 - 10	> 20	Both	About 30 percent of total dwelling stock and about 45 percent in urban areas of Cyprus

India	Rubble stone masonry walls with timber frame and timber roof	**RS3**	1	1	1 or 2	5 - 10	10 - 20	Rural	About 15 percent of housing stock in Maharashtra
India	Reinforced concrete frame building with masonry infill walls designed for gravity loads	**C3M**	5-10	10 (8-20)	1 (extended)	10 - 20	> 20	Both	About 10 percent of building stock in urban India
India	Unreinforced brick masonry walls in mud mortar with flat timber roof	**UFB2**	1	1	1 (extended)	5 - 10	10 - 20	Both	About 17 percent of housing stock in India
India	Unreinforced brick masonry building with reinforced concrete roof slab	**UFB4**	1-4	1	1 or 2	5 - 10	10 - 20	Both	About 20-30 percent housing stock in Maharashtra & Central India
India	Unreinforced brick masonry walls with pitched clay tile roof	**UFB3**	1	1	1 or 2	< 5	> 20	Both	Common in the country
India	Rural mud house with pitched roof	**M2**	1	1 OR 2	1	< 5	5 - 10	Rural	Substantial in numbers
India	Traditional rural house in Kutch region of India (bhonga)	**A2**	1	1	1	< 5	5 - 10	Rural	Very small fraction
India	Low-strength dressed stone masonry buildings	**MS**	1-4	8 (16 - 20)	1	5 - 10	> 20	Both	Throughout India
India	Timber Frame Brick House with Attic	**UFB2**	1	2	1	< 5	5 - 10	Both	Throughout India
Indonesia	Unreinforced clay brick masonry house	**UFB3**	1	1	1	< 5	5 - 10	Rural	Very common in rural Indonesia
Iran	Steel frame with semi-rigid "Khorjini" connections and jack arch roof "Taagh-e-Zarbi".	**S5M**	2-5	2-6	1	5 - 10	10 - 20	Both	About 30-40 percent of urban buildings in Iran & 20-35 percent of rural buildings
Iran	Semi-rigid steel frame with "Khorjinee" connections	**S2M**	4-6	8	1	5 - 10	10 - 20	Both	Common in the country (about 70 percent of steel buildings)
Iran	Confined brick masonry building with concrete tie columns and beams.	**UFB3**	4-6	1	1	< 5	5 - 10	Rural	About 10 percent of building stock in rural Iran
Iran	Adobe House	**A1**	1	1	1	< 5	< 5	Both	Widespread in Middle - Eastern countries and Iran
Iran	Stonework Building with Wooden Joist Roof	**RS2**	1	1	1	< 5	5 - 10	Rural	In some rural areas of Iran
Iran	Four arches (Char taaqi) with dome-roof structures, and unreinforced brick and adobe materials.	**MS or UFB1**	1	1 OR 2	Not applicable	> 20	5 - 10	Both	Used for monuments and generally in desert areas
Iran	Earring system (Shekanj) in dome-roof structures with unreinforced brick and adobe materials.	**UFB1**	Not Available	1	1	< 5	5 - 10	Both	Old heritage type buildings during Persian Empire, very limited
Japan	Single-family wooden house	**W1**	1	1	1	< 5	< 5	Both	About 45.5 percent of housings in Japan
Kyrgyzstan	Precast reinforced concrete frame building with cruciform and linear-beam elements (Series 106)	**PC2H**	9-12	60 (36-120 families per building)	1 or 2	> 20	> 20	Urban	Common in urban areas built after 1975
Kyrgyzstan	Traditional wood frame construction (Yurta)	**W**	1	1	1	5 - 10	5 - 10	Rural	Common in mountain areas of country

Kyrgyzstan	Single-family brick masonry house	**UFB4**	2	1	1	< 5	5 - 10	Both	Most common throughout the country
Kyrgyzstan	Prefabricated concrete panel buildings with monolithic panel joints (seria 105)	**PC1**	5-9	60 (40-80)	1	> 20	> 20	Urban	About 35-40 percent of multistory building stock
Kyrgyzstan	Reinforced concrete frame buildings without beams (seria KUB)	**PC2M**	5-12	36 (10-120)	1	> 20	> 20	Urban	Exists in urban areas of the country
Kyrgyzstan	Buildings with cast-in-situ load-bearing reinforced concrete walls	**C2H**	4-18	54 (20-90 families per building)	1	> 20	> 20	Urban	Widespread in urban areas
Kyrgyzstan	Two-story unreinforced brick masonry building with wooden floors	**UFB2**	2	8 - 16	1	10 - 20	> 20	Urban	5 percent of urban building stock
Kyrgyzstan	Houses with mud walls and thatch roofs	**M2**	1	1	1	< 5	5 - 10	Both	Common in the country
Kyrgyzstan	Buildings with hollow clay tile load-bearing walls and precast concrete floor slabs	**UFB4**	4	64 (1 or 2 per floor)	1	> 20	> 20	Urban	Many buildings can be found throughout Kyrgyzstan
Kyrgyzstan	Load-bearing wall buildings protected with the "sliding belt" base isolation system	**UFB4 with base isolation or PC with base isolation**	9 (5-10)	64 (1 or 2 per floor)	1	> 20	> 20	Urban	Handful in numbers and limited to urban areas
Malaysia	Reinforced concrete frame building with timber roof	**C3L (with timber roof)**	2 (2-4)	10	1	< 5	5 - 10	Both	About 30-40 percent of urban & semi-urban buildings in Malaysia
Nepal	Traditional oval-shaped rural stone house	**RS2**	2 (2-4)	1	1	< 5	5 - 10	Rural	Common in rural areas of the country
Nepal	Uncoursed rubble stone masonry walls with timber floor and roof	**MS**	2 (2-4)	1	1 or 2	5 - 10	5 - 10	Both	Most common traditional housing in rural area
Nepal	Traditional Nawari house in Kathmandu Valley	**UFB2**	3-5	1	1 or 2	5 - 10	10 - 20	Urban	Most common in urban areas
Pakistan	Unreinforced brick masonry residential building	**UFB4**	1-3	1	1 or 2	< 5	5 - 10	Urban	In all major cities of Pakistan except Karachi, 90 percent of residential buildings and 80 percent of all building stock consist of this type
Pakistan	Stone Masonry	**RS2**	Not Available	1	1 or 2	5 - 10	10 - 20	Rural	10 percent in mud mortar with earthen roofs; 40 percent in cement mortar with earthen roof; 10 percent in cement mortar with GI sheet roof; 30 percent with RC roofing

Palestinian Territories	Reinforced concrete frame with infill walls designed for gravity loading	**C3M**	4-5	10 (8-14)	1	5 - 10	> 20	Both	About 30-40 percent building stock in cities in West Bank
Palestinian Territories	Unreinforced concrete and masonry bearing wall construction (designed for gravity loads only)	**MS**	2 (2-4)	4	1	5 - 10	10 - 20	Both	About 20-30 percent building stock in cities in West Bank
Syrian Arab Republic	Reinforced concrete frame with concrete shear walls - dual system	**C2H**	6-15	45 (24-45)	1	> 20	> 20	Urban	Common in big cities in the country
Syrian Arab Republic	Moment resisting frame designed for gravity loads only	**C3L**	3-5	12	1	10 - 20	> 20	Urban	Common in big cities in the country
Taiwan	Street front building with arcade at the first floor (pre-1970s construction)	**C3M**	4-5	10 (varies from 6-10)	1	10 - 20	Other (more than 50)	Both	Widespread in all cities and towns in Taiwan
Taiwan	Street front building with arcade at the first floor (contemporary construction)	**C3M**	4-5	6 - 10	1	10 - 20	Other (more than 50)	Both	Widespread in all cities and towns in Taiwan
Taiwan	High-rise, reinforced concrete buildings with open space at the ground floor	**C1H**	12-20	20 (10-30)	1	10 - 20	Other	Both	Common in new constructions in urban areas
Uzbekistan	Precast reinforced concrete frame panel system of seria IIS-04	**PC2H**	9-12	60	1	> 20	Other	Urban	In Tashkent, a capital city, about 18 percent of residential building and 25 percent of public institution buildings. Common in big cities in Central Asia
Kazakhstan	Prefabricated large panel concrete buildings with two interior longitudinal walls	**PC1**	5-9	81	1	> 20	Other	Urban	Common in southern Kazakhstan

Appendix VI

Estimated average occupancy (day and night) and average number of units within each model building type using Appendix V.

Label	Description	Occupants		Average No. of Units	Source of Data
		Work Hours	Night Hours		
W	**WOOD**	5 to 10	5 to 10	1	EERI (2007)
W1	Wood Frame, Wood Stud, Wood, Stucco, or Brick Veneer	< 5	5 to 10	1	EERI (2007)
W2	Wood Frame, Heavy Members, Diagonals or Bamboo Lattice, Mud Infill	> 20	> 20	7	EERI (2007)
W3	Wood Frame, Prefabricated Steel Stud Panels, Wood or Stucco Exterior Walls	5 to 10	5 to 10	1	By Judgment
W4	Log building	5 to 10	10 to 20	3	EERI (2007)
S	**STEEL**	10 to 20	> 20	6	By Judgment
S1	Steel Moment Frame	10 to 20	> 20	6	By Judgment
S1L	Low-Rise	5 to 10	10 to 20	6	By Judgment
S1M	Mid-Rise	10 to 20	> 20	8	By Judgment
S1H	High-Rise	> 20	500	45	By Judgment
S2	Steel Braced Frame	> 20	> 20	70	By Judgment
S2L	Low-Rise	5 to 10	10 to 20	6	By Judgment
S2M	Mid-Rise	10 to 20	> 20	8	EERI (2007)
S2H	High-Rise	> 20	500	45	By Judgment
S3	Steel Light Frame	> 20	> 20	70	By Judgment
S4	Steel Frame with Cast-in-Place Concrete Shear Walls	> 20	> 20	80	EERI (2007)
S4L	Low-Rise	5 to 10	10 to 20	6	By Judgment
S4M	Mid-Rise	10 to 20	> 20	8	By Judgment
S4H	High-Rise	> 20	500	45	By Judgment
S5	Steel Frame with Unreinforced Masonry Infill Walls	> 20	> 20	70	By Judgment

S5L	Low-Rise	5 to 10	10 to 20	6	By Judgment
S5M	Mid-Rise	5 to 10	10 to 20	4	EERI (2007)
S5H	High-Rise	> 20	500	45	By Judgment
C	**REINFORCED CONCRETE**	10 to 20	> 20	6	By Judgment
C1	Ductile Reinforced Concrete Moment Frame	10 to 20	> 20	6	By Judgment
C1L	Low-Rise	5 to 10	10 to 20	6	By Judgment
C1M	Mid-Rise	> 20	> 20	60	EERI (2007)
C1H	High-Rise	> 20	> 50	30	EERI (2007)
C2	Reinforced Concrete Shear Walls	> 20	> 20	70	EERI (2007)
C2L	Low-Rise	5 to 10	10 to 20	6	By Judgment
C2M	Mid-Rise	5 to 10	> 20	16	EERI (2007)
C2H	High-Rise	> 20	500	45	EERI (2007)
C3	Nonductile Reinforced Concrete Frame with Masonry Infill Walls	> 20	> 20	45	EERI (2007)
C3L	Low-Rise	< 5	5 to 10	12	EERI (2007)
C3M	Mid-Rise	10 to 20	> 20	10	EERI (2007)
C3H	High-Rise	> 20	> 20	30	EERI (2007)
C4	Nonductile Reinforced Concrete Frame without Masonry Infill Walls	10 to 20	> 20	6	By Judgment
C4L	Low-Rise	5 to 10	10 to 20	6	By Judgment
C4M	Mid-Rise	10 to 20	> 20	10	By Judgment
C4H	High-Rise	> 20	500	45	By Judgment
C5	Steel Reinforced Concrete (Steel Members Encased in Reinforced Concrete)	10 to 20	> 20	6	By Judgment
C5L	Low-Rise	5 to 10	10 to 20	6	By Judgment
C5M	Mid-Rise	10 to 20	> 20	10	By Judgment
C5H	High-Rise	> 20	500	45	By Judgment
PC1	Precast Concrete Tilt-Up Walls	> 20	> 20	150	EERI (2007)
PC2	Precast Concrete Frames with Concrete Shear Walls	10 to 20	> 20	6	By Judgment
PC2L	Low-Rise	5 to 10	10 to 20	6	By Judgment
PC2M	Mid-Rise	> 20	> 20	100	EERI (2007)
PC2H	High-Rise	> 20	> 20	60	EERI (2007)

RM	**REINFORCED MASONRY**	< 5	5 to 10	2	By Judgment
RM1	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	< 5	5 to 10	2	By Judgment
RM1L	Low-Rise	< 5	> 20	20	By Judgment
RM1M	Mid-Rise (4+ stories)	10 to 20	> 20	6	By Judgment
RM2	Reinforced Masonry Bearing Walls with Concrete Diaphragms	10 to 20	> 20	6	By Judgment
RM2L	Low-Rise	< 5	> 20	20	EERI (2007)
RM2M	Mid-Rise	10 to 20	> 20	6	EERI (2007)
RM2H	High-Rise	> 20	> 20	60	By Judgment
MH	**Mobile Homes**	< 5	5 to 10	2	By Judgment
M	**MUD WALLS**	< 5	5 to 10	2	By Judgment
M1	Mud Walls without Horizontal Wood Elements	< 5	5 to 10	2	By Judgment
M2	Mud Walls with Horizontal Wood Elements	< 5	5 to 10	2	EERI (2007)
A	**ADOBE BLOCK (UNBAKED DRIED MUD BLOCK) WALLS**	< 5	5 to 10	1	By Judgment
A1	Adobe Block, Mud Mortar, Wood Roof and Floors	< 5	5 to 10	1	EERI (2007)
A2	Same as A1, Bamboo, Straw, and Thatch Roof	< 5	5 to 10	1	EERI (2007)
A3	Same as A1, Cement-Sand Mortar	< 5	5 to 10	1	By Judgment
A4	Same as A1, Reinforced Concrete Bond Beam, Cane and Mud Roof	5 to 10	5 to 10	1	EERI (2007)
A5	Same as A1, with Bamboo or Rope Reinforcement	< 5	5 to 10	1	By Judgment
RE	**RAMMED EARTH/PNEUMATICALLY IMPACTED STABILIZED EARTH**	< 5	5 to 10	1	EERI (2007)
RS	**RUBBLE STONE (FIELD STONE) MASONRY**	< 5	5 to 10	1	By Judgment
RS1	Local Field Stones Dry Stacked (No Mortar). Timber Floors. Timber, Earth, or Metal Roof.	< 5	5 to 10	1	By Judgment
RS2	Same as RS1 with Mud Mortar.	< 5	5 to 10	1	EERI (2007)
RS3	Same as RS1 with Lime Mortar.	5 to 10	10 to 20	2	EERI (2007)
RS4	Same as RS1 with Cement Mortar, Vaulted Brick Roof and Floors	< 5	5 to 10	1	EERI (2007)

RS5	Same as RS1 with Cement Mortar and Reinforced Concrete Bond Beam.	5 to 10	10 to 20	2	By Judgment
DS	**RECTANGULAR CUT STONE MASONRY BLOCK**	< 5	5 to 10	2	By Judgment
DS1	Rectangular Cut Stone Masonry Block with Mud Mortar, Timber Roof and Floors	< 5	5 to 10	2	EERI (2007)
DS2	Same as DS1 with Lime Mortar	< 5	5 to 10	2	By Judgment
DS3	Same as DS1 with Cement Mortar	< 5	5 to 10	2	By Judgment
DS4	Same as DS2 with Reinforced Concrete Floors and Roof	< 5	5 to 10	2	By Judgment
UFB	**UNREINFORCED FIRED BRICK MASONRY**	5 to 10	10 to 20	1	By Judgment
UFB1	Unreinforced Brick Masonry in Mud Mortar without Timber Posts	< 5	5 to 10	1	EERI (2007)
UFB2	Unreinforced Brick Masonry in Mud Mortar with Timber Posts	5 to 10	10 to 20	1	EERI (2007)
UFB3	Unreinforced Fired Brick Masonry, Cement Mortar, Timber Flooring, Timber or Steel Beams and Columns, Tie Courses (Bricks Aligned Perpendicular to the Plane of the Wall)	5 to 10	10 to 20	5	EERI (2007)
UFB4	Same as UFB3, but with Reinforced Concrete Floor and Roof Slabs	5 to 10	> 20	64	EERI (2007)
UCB	**UNREINFORCED CONCRETE BLOCK MASONRY, LIME/CEMENT MORTAR**	5 to 10	> 20	8	EERI (2007)
MS	**MASSIVE STONE MASONRY IN LIME/CEMENT MORTAR**	5 to 10	> 20	13	EERI (2007)
TU	**PRECAST CONCRETE TILT-UP WALLS** (same as HAZUS Type PC1 in Developing and Undeveloped Countries)	5 to 10	> 20	8	By Judgment
INF	**INFORMAL CONSTRUCTIONS** (parts of Slums/Squatters) Constructions Made of Wood/Plastic Sheets/Galvanized Iron sheets/Light Metal or Composite etc., not Confirming to Engineering Standards.	< 5	5 to 10	1	By Judgment

UNK	Unknown Category (Not specified)	< 5	5 to 10	1	By Judgment

Appendix VII

Refer Electronic Supplement – Jaiswal and Wald (2008) PAGER Inventory Database v1.3.xls. (This link contains the most updated version of this database).

Table 1. Tabulation of the types of data sources, their parameters, assigned quality ratings, and their coverage

Sr. No.	Source of Data	Building Stock Distribution	Quality	Global Coverage	Overall Data Source Rating
1.	**World Housing Encyclopedia** (developed by EERI, USA- http://www.world-housing.net/)	**1. Residential:** a. Construction type b. Occupancy (D/N/T)	 High Medium	110 residential construction types in 37 countries. Exact fraction of each housing type in a given country is not known. The day and night time occupancy by construction type is available.	Medium
2.	**UN Database** (statistical database compiled by UN agencies; UN 1993 and UN-HABITAT 2007)	**1. Residential:** a. Housing by type of dwelling b. Housing by Construction Material	 Medium Low	44 countries with construction type description based on external walls and 96 countries with type of housing units. About 110 countries with average occupancy estimated based on total building stock.	Low
3.	**Census of Housing** (data compiled from housing census statistics)	**1. Residential:** a. Housing by type of dwelling b. Housing by construction material c. Occupancy (D/N/T) **2. Nonresidential:** a. Dwelling type b. Construction type c. Occupancy (D/N/T)	 High Medium Low High Medium Low	197 countries conducted housing census in 1990. Several countries do not publish housing statistics even though housing census was conducted.	Medium
4.	**Published Literature** (such as, research articles;	**1. Residential:**		About 10 countries have been identified that contains high	High

	reports; nonproprietary information)	a. Housing by type of dwelling b. Housing by construction material c. Occupancy (D/N/T) **2. Nonresidential:** a. Dwelling type b. Construction type c. Occupancy (D/N/T)	High High Low High Medium Medium	quality information based on conducting survey and verification of other published information e.g., census/ tax assessor's data. The day and night time occupancy by construction type is not available.	
5.	**WHE-PAGER Survey** (http://www.world-housing.net)	**1. Residential:** a. Construction type c. Occupancy (D/N/T) **2. Nonresidential:** a. Construction type b. Occupancy (D/N/T)	 High High High High	Inventory information for about 22 countries has been gathered in the first phase of WHE-PAGER expert opinion survey. In order to facilitate their judgment, country-specific inventory information gathered from general internet research and housing censuses was provided to these experts. It is expected that the contributions sought from these expert will help to update the existing PAGER compilations for their respective countries.	High

Notes: High quality refers to data compiled from engineering or telephonic surveys, field visits for ground-truth, or data compilations from local engineering experts; Medium quality refers to data compiled by general field surveys and assignments generally not based on engineering standards; Low quality refers to data compiled by non-engineering agencies and was not specifically meant for engineering risk analysis

Table 2. Housing units by construction material of external walls in the year 2004 for Tanzania from the UN (2007) database

Serial No.	Description of Construction Material (wall)	Fraction of housing units (in percent)
1.	Grass	0.2
2.	Poles and mud	14.7
3.	Sundried bricks	18.7
4.	Baked bricks	13.8
5.	Timber	0.5
6.	Cement bricks	51.0
7.	Stone	1.0

Table 3. List of countries, source of contact, and web links for countries with housing census data

Serial No.	Country	Source	Year	Web Link	Visit Date
1	Pakistan	Pakistan Population Census Organization	1998	*http://www.statpak.gov.pk/depts/pco/statistics/other_tables/housing_units_by_construction_material.pdf*	May 01, 2007
2	Philippines	National Statistics Office	2000	*http://www.nscb.gov.ph/secstat/d_popn.asp*	May 01, 2007
3	Nepal	Nepal Central Bureau of Statistics	2004	*http://www.worldbank.org/html/prdph/lsms/country/nepal2/docs/NLSS%20II%20Report%20Vol%201.pdf*	May 01, 2007
4	Japan	Statistical Bureau	2003	*http://www.stat.go.jp/english/data/jyutaku/1503.htm*	May 01, 2007
5	Thailand	National Statistics Office Thailand	2000	*http://web.nso.go.th/pop2000/indiregion/wholetab4.htm*	May 01, 2007
6	Mexico	Housing Study Report	1995	*http://www.jchs.harvard.edu/publications/international/SOM_97.pdf*	May 01, 2007
7	Australia	Geoscience Australia	2007	written communication	--
8	Lithuania	Statistics Lithuania	2000	http://www.std.lt	Oct. 07 2007
9	Iran	Statistical Center of Iran	2005	http://www.sci.org.ir	Dec. 04 2007

Table 4. (a) Census data compiled by the National Statistical Office of the Government of the Philippines for housing inventory by construction material, (b) Housing Census data showing distribution of housing units by construction material (wall and roof construction) for Pakistan

Number of Occupied Housing Units by Construction Materials of the Outer Walls and Roof: 2000

Construction Materials of the Outer Walls	Total Number of Occupied Housing Units	Construction Materials of the Roof							
		Galvanized Iron/ Aluminum	Tile/ Concrete/ Clay Tile	Half Galvanized Iron/ Half-Concrete	Wood	Cogon/ Nipa/ Anahaw	Makeshift Salvaged/ Improv-ised Materials	Asbestos/ Others	Not Reported
Total	**14,891,127**	**10,066,730**	**138,050**	**689,226**	**306,121**	**3,315,374**	**107,786**	**57,300**	**210,540**
Concrete/ brick/ stone	4,587,978	4,323,530	100,987	67,627	10,657	73,176	2,934	9,067	-
Wood	3,381,339	2,263,524	10,670	70,193	227,549	786,637	12,031	10,735	-
Half concrete/ brick/ stone and half wood	2,816,272	2,146,675	17,607	483,460	23,369	137,000	3,995	4,166	-
Galvanized iron/ aluminum	144,234	118,741	1,307	13,389	3,827	6,159	539	272	-
Bamboo/ sawali/ cogon/ nipa	3,399,180	1,044,744	5	43,592	35,625	2,238,453	15,775	20,852	134
Asbestos	8,823	5,623	1,321	493	262	-	-	1,121	3
Glass	4,895	3,594	669	260	121	-	-	249	2
Makeshift/ salvaged/ improvised materials	181,769	66,216	15	3,030	1,212	38,497	70,817	1,884	98
Others/not reported	352,293	85,186	4,536	6,466	2,948	33,167	1,129	8,634	210,227
No walls	14,344	8,897	933	716	551	2,285	566	320	76

Source: National Statistics Office.

(a)

HOUSING UNITS BY CONSTRUCTION MATERIAL

(In percent)

Administrative Units	Material used in Outer Walls				Material Used in Roofs			
	Baked Bricks/ Blocks/Stone	Un-Baked Bricks/ Earth Bound	Wood/ Banboo	Others	RCC/RBC	Cement/ Iron Sheet	Wood/ Bamboo	Others
Pakistan	58.46	34.48	5.42	1.64	21.39	13.07	57.35	8.18
Rural	45.96	44.69	7.20	2.14	10.43	10.05	69.76	9.76
Urban	85.76	12.16	1.53	0.54	45.35	19.69	30.23	4.74

(b)

Table 5. List of countries with inventory data from published country-specific resources, articles, and reports

Sr. No.	Country	Vintage	Data Source (direct/inferred)
1	Albania	2001	2001 Albania Housing Census data (inferred/ not specific)
2	Algeria	1983	Petrovski (1983)
3	Armenia	2007	Expert Opinion 2007
4	Iran	2005	Ghafory-Ashtiany and Mousavi (2005)
5	Iraq	1983	Petrovski (1983)
6	Jordan	1983	Petrovski (1983)
7	Saudi Arabia	1983	Petrovski (1983)
8	Sudan	1983	Petrovski (1983)
9	Syrian Republic	1983	Petrovski (1983)
10	California (U.S.A.)	2002	HAZUS inventory data (FEMA, 2006)
11	United States of America (U.S.A.)	2002	HAZUS inventory data (FEMA, 2006)
12	Italy	2006	Dolce, Kappos and others (2006)
13	Turkey	2002	Bommer, Spence and others (2002)

Table 6. Residential construction type distribution for several Middle-Eastern countries, from Petrovski (1983)

Sr. No.	Country	Description	PAGER Struct. type	Fraction of Resi. Buildings
1	Algeria	Traditional construction (Adobe, brick or stone masonry)	UFB	15%
		Modern construction (RC/Steel frame with brick infill or combined structural system)	C3L	85%
		Modern construction with seismic protection	C1L	0%
2	Sudan	Traditional construction (Adobe, brick or stone masonry)	A	80%
		Modern construction (RC/Steel frame with brick infill or combined structural system)	C3L	20%
		Modern construction with seismic protection	C1L	0%
3	Saudi Arabia	Traditional construction (Adobe, brick or stone masonry)	UFB	0%
		Modern construction (RC/Steel frame with brick infill or combined structural system)	C3L	100%
		Modern construction with seismic protection	C1L	0%
4	Jordan	Traditional construction (Adobe, brick or stone masonry)	UFB	70%
		Modern construction (RC/Steel frame with brick infill or combined structural system)	C3L	30%
		Modern construction with seismic protection	C1L	0%
5	Syria	Traditional construction (Adobe, brick or stone masonry)	UFB	60%
		Modern construction (RC/Steel frame with brick infill or combined structural system)	C3L	40%
		Modern construction with seismic protection	C1L	0%
6	Iraq	Traditional construction (Adobe, brick or stone masonry)	UFB	80%
		Modern construction (RC/Steel frame with brick infill or combined structural system)	C3L	20%
		Modern construction with seismic protection	C1L	0%

Table 7. Housing stock distribution based on UN-HABITAT (2007) compiled for Peru

Sr. No.	Description used for defining fraction of housing units by construction material for outer wall (UN-HABITAT, 2007)	Mapping of construction type to equivalent PAGER Structure Type	Fraction of total residential housing stock (the exact decimal places of estimate are based on original data)
1.	11 Madera	W	3.08 %
2.	12 Piedra con barro	RS2	0.12%
3.	13 Tripley	INF	0.93%
4.	14 Estera	W	0.57%
5.	21 Adobe o tapia	A	19.41%
6.	22 Quincha (cañas con barro)	M2	0.94%
7.	31 Ladrillo o bloque de cemento	UCB	73.15%
8.	32 Piedra o sillar con cal o cemento	DS3	1.33%
9.	96 Other	UNK	0.47%

Table 8. Housing stock distribution based on the 2000 Census of Population and Housing compiled for Australia

Sr. No.	Residence by type of wall (Edwards, written communication)	Geoscience Australia Structural Model (Edwards, Robinson and others, 2004)	PAGER Structure Type	Fraction of total residential housing stock (the exact decimal places of estimate are based on original data)
1.	Double brick	URM	UFB	52.86%
2.	Brick Veneer	W1B	W	6.21%
3.	Timber	W1	W1	26.07%
4.	Fibro/asbestos cement	-NA-	INF	14.86%

Table 9. Housing stock distribution based on the 1990 Census of Population and Housing compiled for El Salvador

Sr. No.	Residential housing type data of El Salvador	PAGER Structure Type	Fraction of housing stock in percentage
1.	Adobe	A	1%
2.	Stone (block) masonry	DS	10%
3.	Brick masonry	UFB	37%
4.	Wood frame with poor infill walls	W2	37%
5.	Wood frame with wood panel walls	W1	15%

Table 10. Housing stock distribution based on the Census of Population and Housing (2001) compiled for Indonesia

Sr. No.	Residential housing type obtained from census data	PAGER Structure Type	Fraction of housing stock in percentage
1.	Unreinforced clay brick masonry with timber roof	UFB3	30%
2.	Stone masonry walls with timber roof	RS1	30%
3.	Mid rise reinforced concrete frame with infilled masonry walls	C3M	20%
4.	Timber frame with mud walls	W2	10%
5.	Informal	INF	10%

Table 11. Housing stock distribution based on Ghafory-Ashtiany and Mousavi (2005) for the city of Bam, Iran

Sr. No.	Residential housing type data for Bam in Iran (Ghafory-Ashtiany and Mousavi, 2005)	PAGER Structure Type	Fraction of housing stock in percentage (the exact decimal places of estimate are based on original data)
1.	Sun-dried bricks and clay	A	53.2%
2.	Brick only	UFB	3.5%
3.	Brick and Wood	UFB2	1.9%
4.	Brick and Steel	UFB6	40.6%
5.	Concrete structures	C3L	0.8%

Table 12. Distribution of residential building stock in Italy

Sr. No.	Description of residential housing type data for Southern Italy (Dolce, Kappos and others, 2006)	Type	PAGER Structure Type	Fraction of building stock (by volume)	Fraction of building stock (by number)
1.	Dual, poor design, low	RC1I-L	C3L	1.8%	4.6%
2.	Dual, good design, low	RC1E-L	C2L	0.6%	1.3%
3.	Dual, poor design, medium	RC1I-M	C3M	1.7%	0.8%
4.	Dual, good design, medium	RC1E-M	C2M	0.4%	0.2%
5.	Dual, poor design, tall	RC1I-H	C3H	1.4%	0.1%
6.	Dual, good design, tall	RC1E-H	C2H	0.4%	0.0%
7.	Frame, poor design, low	RC2I-L	C4L	5.8%	6.5%
8.	Frame, good design, low	RC2E-L	C1L	5.2%	7.8%
9.	Frame, poor design, medium	RC2I-M	C4M	27.8%	8.9%
10.	Frame, good design, medium	RC2E-M	C1M	10.0%	3.4%
11.	Frame, poor design, tall	RC2I-H	C4H	13.6%	2.0%
12.	Frame, good design, tall	RC2E-H	C1H	4.1%	0.7%
13.	Stone masonry, low	SM-L	RS	2.9%	13.6%

14.	Stone masonry, medium	SM-M	RS	5.9%	9.8%
15.	Stone masonry, high	SM-H	MS	6.6%	2.9%
16.	Brick masonry, low	BM-L	UFB	4.5%	27.9%
17.	Brick masonry, medium	BM-M	UFB	4.1%	7.4%
18.	Brick masonry, high	BM-H	UFB	2.5%	0.6%
19.	Steel structures of any type	Steel	S	0.4%	1.1%
20.	Other types of buildings	Other	UNK	0%	0.3%

Table 13. Distribution of residential building stock in Japan

Sr. No.	Residential housing type data for Japan (Statistics Bureau Japan, 2003).	PAGER Structure Type	Fraction of housing stock in percentage
1.	Wooden	W2	31.69%
2.	Wooden and fire-proofed	W1	29.68%
3.	Reinforced steel framed concrete	C3	31.89%
4.	Steel framed	S3	6.44%
5.	Others	UNK	0.3%

Table 14. Distribution of residential building stock in Mexico

Sr. No.	Residential housing type	PAGER Structure Type	Fraction of housing stock in percentage (1990)	Fraction of housing stock in percentage (2000)
1.	Brick/Stone	UFB	69.9%	75.7%
2.	Adobe	A	14.7%	None
3.	Wood	W	8.2%	None
4.	Other	UNK	7.2%	24.3%

Table 15. Distribution of residential building stock in Nepal

Sr. No.	Residential housing type data for Nepal (Nepal Central Bureau of Statistics, 2004)	PAGER Structure Type	Fraction of housing stock in percentage
1.	Wood/branches	W	18.5%
2.	Mud bonded bricks/stones	UFB1	47.5%
3.	Cement bonded bricks/stones and concrete	UFB3	18.3%
4.	Others	UNK	15.7%

Table 16. Distribution of residential building stock in New Zealand

Sr. No.	Residential housing type data for New Zealand (Dowrick, 1998)	PAGER Structure Type	Fraction of housing stock in percentage (by judgment)
1.	Timber buildings	W1	78%
2.	Reinforced concrete building	C2	8%
3.	Unreinforced brick masonry buildings	UFB	7%
4.	Steel buildings	S	2%
5.	Reinforced masonry	RM	5%

Table 17. Distribution of residential building stock in Taiwan

Sr. No.	Residential housing type data for Nantau and Taichung County in Taiwan (Tien, Juang and others, 2002)	PAGER Structure Type	Fraction of housing stock in percentage
1.	Mud brick residence	A	10.67%
2.	Masonry and reinforced masonry buildings	RM	43.75%
3.	Reinforced concrete buildings	C3M	37.51%
4.	Composite construction (Steel and RC)	C5	0.33%
5.	Steel frames	S3	3.63%
6.	Others	UNK	4.11%

Table 18. Distribution of residential building stock in Philippines

Sr. No.	Residential housing type data for Philippines (Housing Census, 2000)	PAGER Structure Type	Fraction of housing stock in percentage
1.	Wood	W	22.7%
2.	Bamboo/sawali/cogon/nipa (poor-quality wood construction in rural area)	W2	22.8%
3.	Half wood and half concrete/brick/stone category	W	18.9%
4.	Brick, stone, or concrete walls	UFB	30.8%
5.	Others	UNK	4.8%

Table 19. Distribution of residential building stock in Turkey

Sr. No.	Residential housing type data for Turkey	PAGER Structure Type	Urban (68.2%)	Rural (31.8%)	Fraction of housing stock in percentage
1.	Timber frame	W	< 1%	< 1%	0.66%
2.	Weak Masonry (adobe, rubble masonry)	A	7%	9%	7.64%
3.	Brick/block unreinforced masonry with timber floors	UFB2	19%	26%	21.23%
4.	Brick/block unreinforced masonry with concrete floors	UFB4	17%	21%	18.27%
5.	RC frame with masonry infill – 1 to 3 stories, poor seismic design	C3L	44% (41.5%)	36%	39.75%
6.	RC frame with masonry infill – 4 to 7 stories, poor seismic design	C3M	4%	3%	3.68%
7.	RC frame with masonry infill – 8 or more stories, poor seismic design	C3H	6%	1%	4.41%
8.	RC frame with masonry infill – 1 to 3 stories, good seismic design	C1L	1%	< 1%	1.00%
9.	RC frame with masonry infill – 4 to 7 stories, good seismic design	C1M	< 1%	0	0.34%
10.	RC frame with masonry infill – 8 or more stories, good seismic design	C1H	< 1%	0	0.34%
11.	RC shear wall – 4 to 7 stories	C2M	1%	< 1%	1.00%
12.	RC shear wall – 8 or more stories	C2H	2%	1%	1.68%
13.	Single story industrial shed with light steel truss roof pinned to cantilever RC or steel stanchions	S3	0%	0%	0%
14.	Single story industrial shed with precast concrete roof	PC1	0%	0%	0%

Table 20. Distribution of California building stock as obtained from the HAZUS (FEMA, 2006) inventory database

Sr. No.	Building Type	HAZUS Structure Type	PAGER Structure Type	Fraction of Buildings
1	Wood, Light Frame (= 5,000 sq. ft.)	W1	W1	91%
2	Wood, Commercial and Industrial Wood (>5,000 sq. ft.)	W2	W2	0%
3	Steel Moment Frame Low-Rise	S1L	S1L	0%
4	Steel Moment Frame Mid-Rise	S1M	S1M	0%
5	Steel Moment Frame High-Rise	S1H	S1H	0%
6	Steel Braced Frame Low-Rise	S2L	S2L	0%
7	Steel Braced Frame Mid-Rise	S2M	S2M	0%
8	Steel Braced Frame High-Rise	S2H	S2H	0%
9	Steel Light Frame	S3	S3	0%
10	Steel Frame with Cast-in-Place Concrete Shear Walls Low-Rise	S4L	S4L	0%
11	Steel Frame with Cast-in-Place Concrete Shear Walls Mid-Rise	S4M	S4M	0%
12	Steel Frame with Cast-in-Place Concrete Shear Walls High-Rise	S4H	S4H	0%
13	Steel Frame with Unreinforced Masonry Infill Walls Low-Rise	S5L	S5L	0%
14	Steel Frame with Unreinforced Masonry Infill Walls Mid-Rise	S5M	S5M	0%
15	Steel Frame with Unreinforced Masonry Infill Walls High-Rise	S5H	S5H	0%
16	Concrete Moment Frame Low-Rise	C1L	C1L	0%
17	Concrete Moment Frame Mid-Rise	C1M	C1M	0%
18	Concrete Moment Frame High-Rise	C1H	C1H	0%
19	Concrete Shear Walls Low-Rise	C2L	C2L	1%
20	Concrete Shear Walls Mid-Rise	C2M	C2M	0%
21	Concrete Shear Walls High-Rise	C2H	C2H	0%

22	Concrete Frame with Unreinforced Masonry Infill Walls Low-Rise	C3L	C3L	0%
23	Concrete Frame with Unreinforced Masonry Infill Walls Mid-Rise	C3M	C3M	0%
24	Concrete Frame with Unreinforced Masonry Infill Walls High-Rise	C3H	C3H	0%
25	Precast Concrete Tilt-Up Walls	PC1	PC1	0%
26	Precast Concrete Frames with Concrete Shear Walls Low-Rise	PC2L	PC2L	0%
27	Precast Concrete Frames with Concrete Shear Walls Mid-Rise	PC2M	PC2M	0%
28	Precast Concrete Frames with Concrete Shear Walls High-Rise	PC2H	PC2H	0%
29	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Low-Rise	RM1L	RM1L	2%
30	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms Mid-Rise	RM1M	RM1M	0%
31	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Low-Rise	RM2L	RM2L	0%
32	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms Mid-Rise	RM2M	RM2M	0%
33	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms High-Rise	RM2H	RM2H	0%
34	Unreinforced Masonry Bearing Walls Low-Rise	URML	UFB	0%
35	Unreinforced Masonry Bearing Walls High-Rise	URMM	UFB	0%
36	Manufactured Home	MH	MH	6%

Table 21. List of countries that provide inventory data obtained during WHE-PAGER survey and the name of the experts

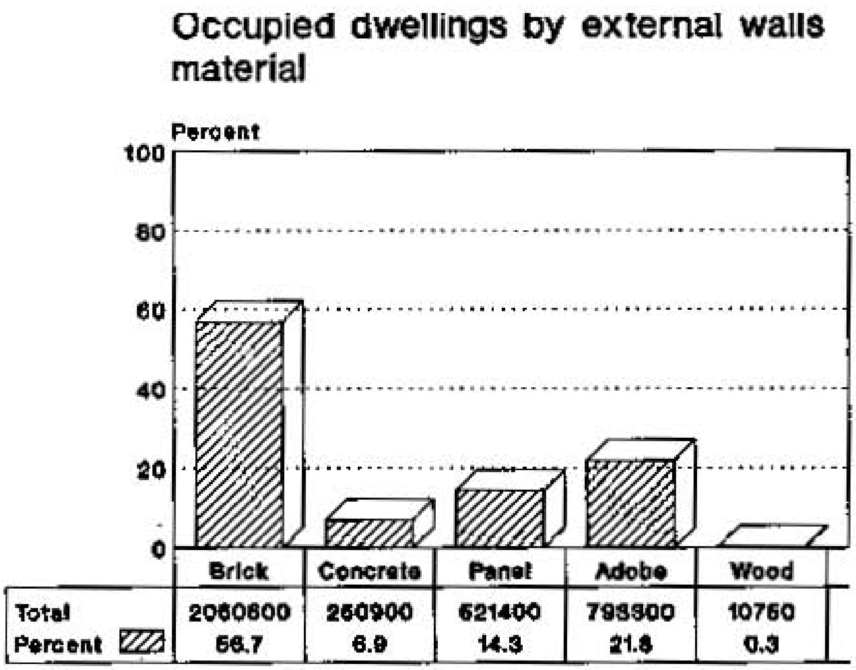
Sr. No.	Country	Name of Expert
1.	Algeria	Mohammed N. Farsi, Farah Lazzali
2.	California	Craig Comartin
3.	Chile	María Ofelia Moroni
4.	China	SUN Baitao/Zhang GUIXIN/Chen Honfu, Institute of Engineering Mechanics CEA
5.	Colombia	Luis G. Mejia
6.	Cyprus	Vsevolod Levtchitch
7.	France	THIBAULT Christian
8.	Germany	Sergey Tyagunov, Lothar Stempniewski, Christian Münich
9.	India	C.V.R. Murty
10.	Indonesia	Sugeng Wijanto
11.	Ireland	Robin Spence
12.	Italy	Agostino Goretti
13.	Japan	Charles Scawthorn
14.	Mexico	Sergio M. Alcocer
15.	Nepal	Jitendra Kumar Bothara
16.	Pakistan	Qaisar Ali
17.	Peru	Alejandro Muñoz
18.	Spain	Alex H. Barbat
19.	Switzerland	Kerstin Pfyl-Lang
20.	Thailand	Chitr Lilavivat
21.	Turkey	Polat Gülkan/Ahmet Yakut
22.	United Kingdom	Robin Spence

Table 22. WHE-PAGER survey response for Japan, contributed by Dr. Charles Scawthorn from Kyoto University, Japan

JAPAN: Summary of Building Types, Vulnerability to Collapse and Occupancy

Completed by: Charles Scawthorn, Kyoto University, Katsura Campus, Kyoto, Japan 606
E-mail address:cscawthorn@att.net

List construction type *(refer to Tables 2 and 3 for suggested categories, sources of data to help answer this question)*	Probability of collapse (%) building type when subjected to the specified shaking intensity *(refer to instructions on page 5)*				Fraction of population who LIVES in this building type *(refer to instructions on page 5 for help in estimating)*		Fraction of population who WORKS in this building type *(refer to instructions on page 5 for help in estimating)*		Peak average number of occupants per building *(refer to instructions on page 5 for help in estimating)*	
	MMI/MSK IX (~0.65-1.24g)	MMI/MSK VIII (~0.34-0.65g)	MMI/MSK VII (~0.18-0.34g)	MMI/MSK VI (~0.092-.18g)	urban areas	rural areas	Urban areas	rural areas	day	night
9 Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs	30	20	5	0.1			-	-	200	-
10 Confined brick/block masonry with concrete posts/tie columns and beams	20	5	1	-			3	3	100	10
15 RC MRF Designed with seismic features (various ages)	10	2	1	-			10	10	1000	100
16 RC MRF Frame with unreinforced masonry infill walls	10	5	1	-			-	-	1000	100
17 RC MRF Flat slab structure	15	3	1	-			5	5	300	50
19 RC MRF Frame with concrete shear walls-dual system	4	1	-	-			10	-	500	100
21 RC SW Walls cast in-situ	2	1	-	-	30	2	10	5	1000	1000
24 STL MRF With cast in-situ concrete walls	2	1	-	-			20	10	1000	1000
25 STL MR with lightweight partitions	4	1	-	-			20	10	1000	1000
26 STL CBF	4	1	-	-			10	10	1000	1000
30 WOODEN; PRE-1981	50	10	5	2	30	50	8	17	3	6
30 WOODEN; POST-1981	15	5	1	-	40	48	4	30	3	6



Source: Hungarian Central Statistical Office, 1990 Population Census - Detailed Data Based on a 2 Percent Representative Sample, Budapest, 1992

Figure 1. Histogram showing housing units by construction material for Hungary

Figure 2. Schematic overview flowchart of the PAGER inventory development methodology

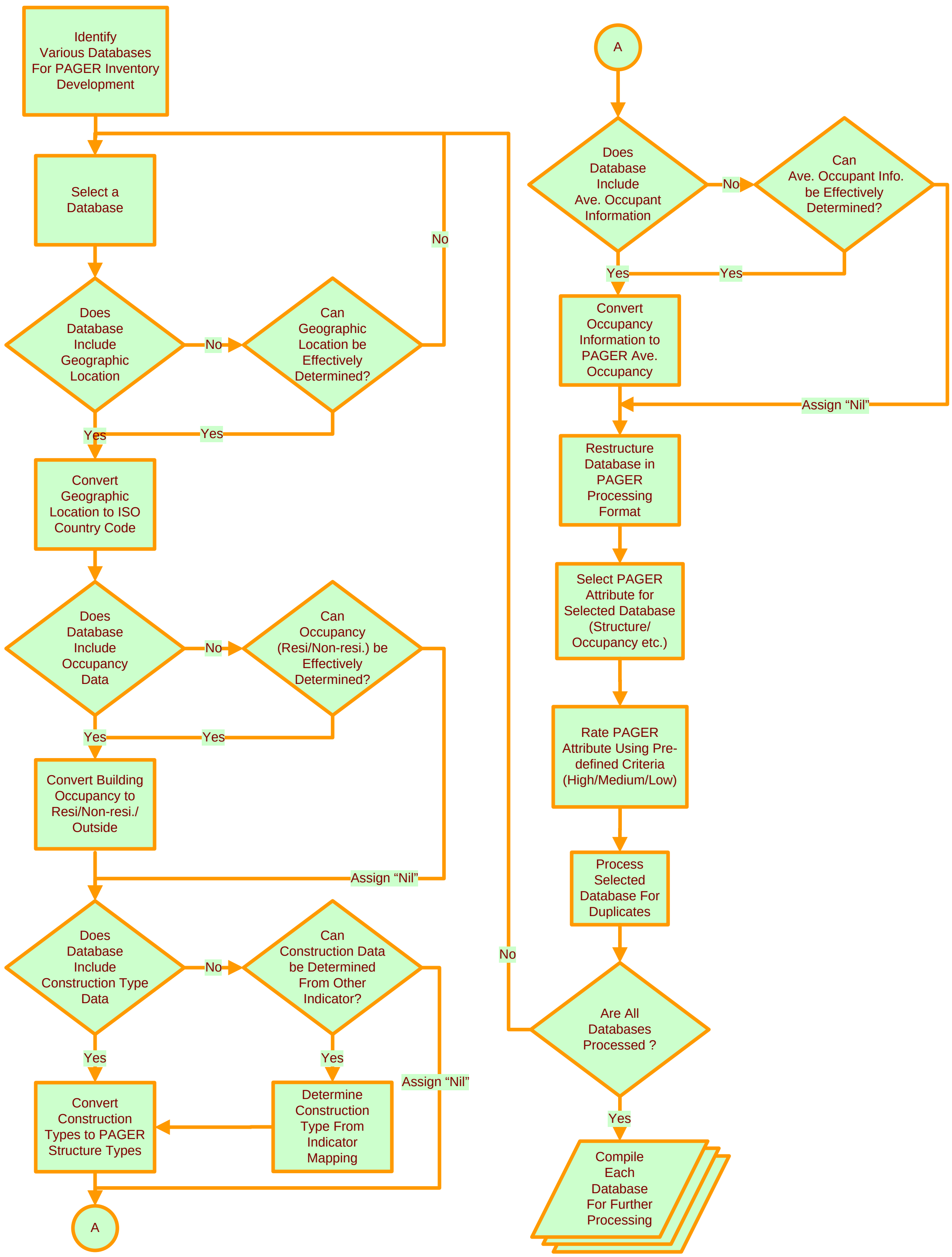


Figure 3. Schematic flowchart of the PAGER inventory development methodology (Phase I – Population of databases and ratings)

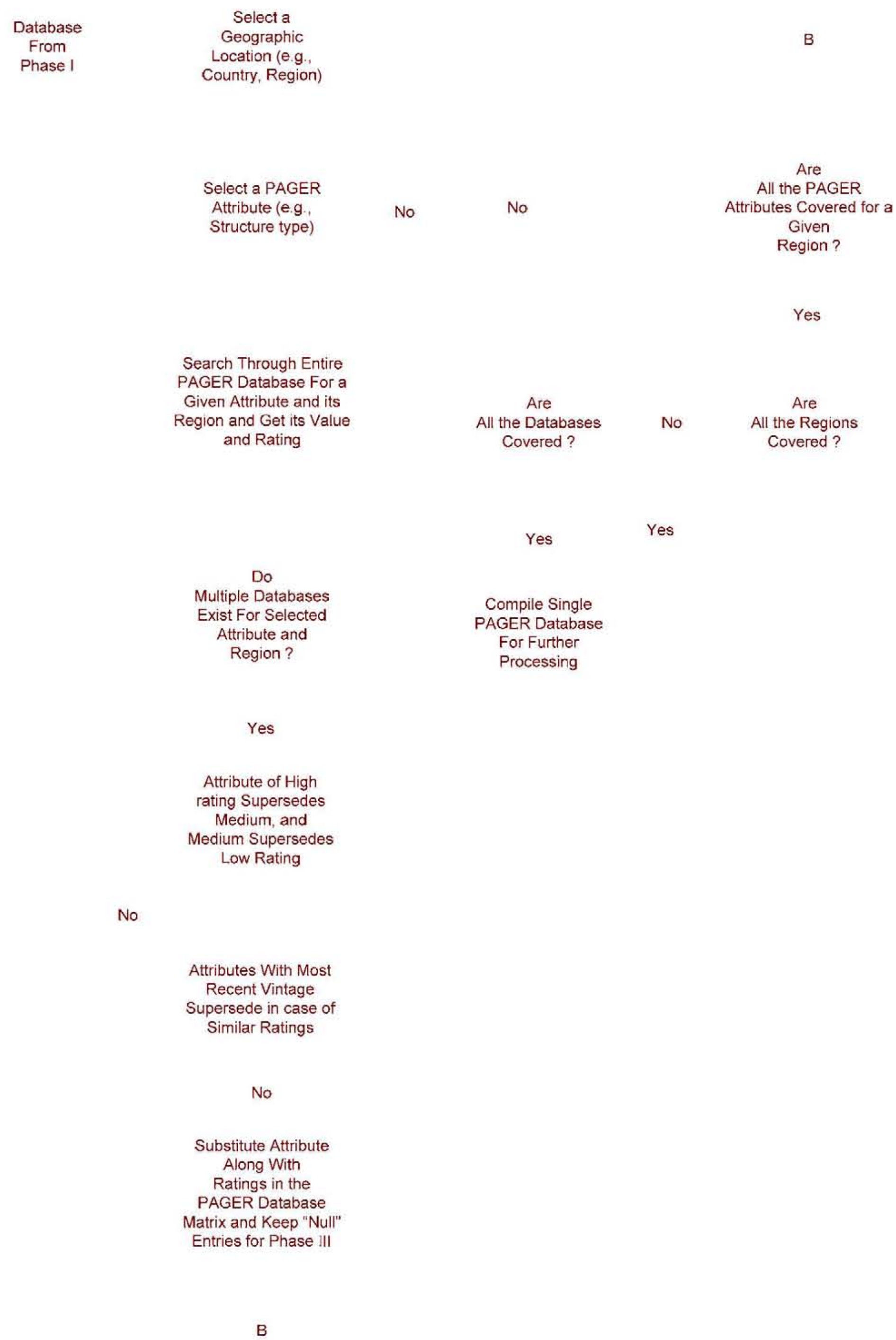


Figure 4. Schematic flowchart of the PAGER Inventory Development Methodology (Phase II - Merging of Databases)

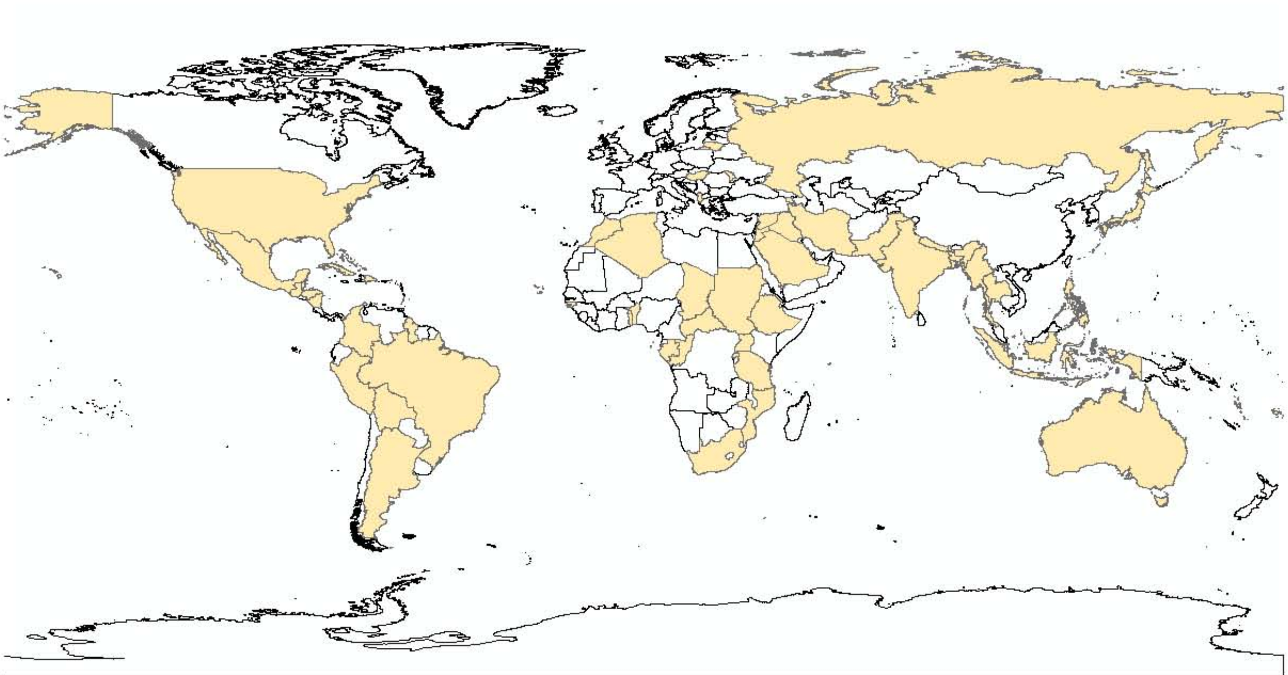


Figure 5. Map showing geographic coverage by country of the building inventory data from different sources aggregated in Phase II

Figure 6. Map showing the housing stock distribution pattern of Iran, identified as a possible representative building stock distribution for Afghanistan (where data is not available) based on recent vintage and rating of Iran over data from Pakistan

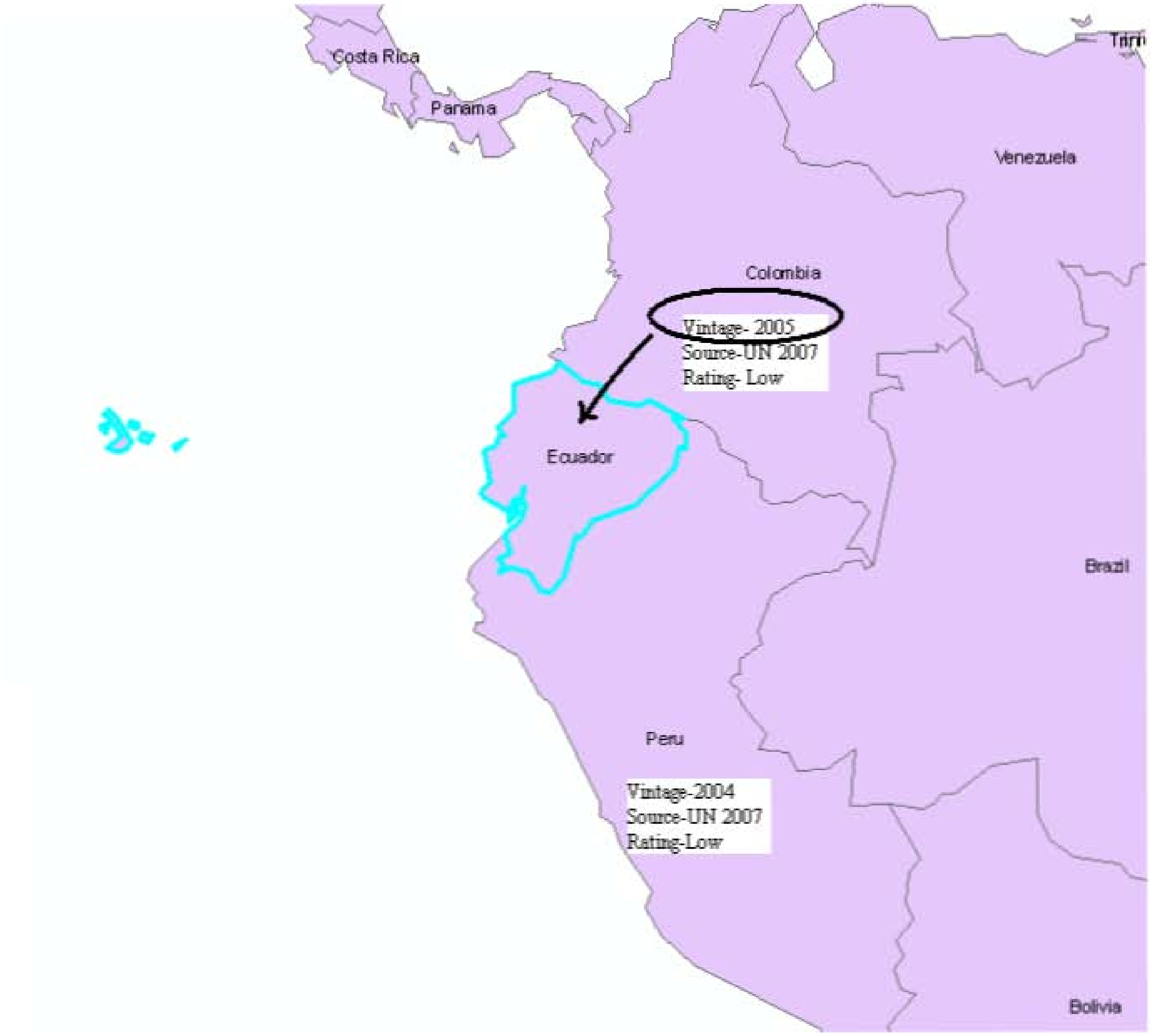


Figure 7. Map showing identification of most representative neighbor for Ecuador from all neighboring countries

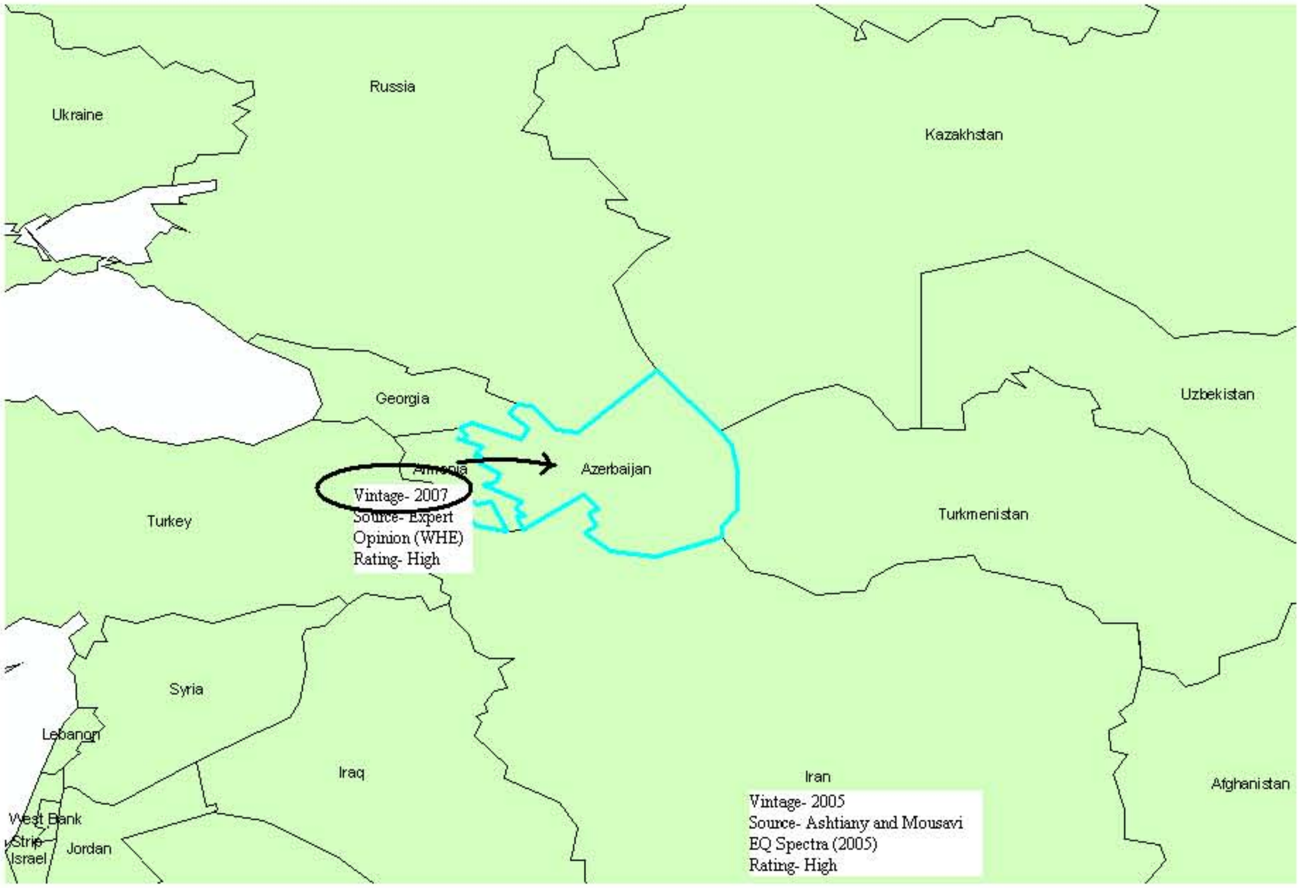


Figure 8. Map showing the building stock distribution in Armenia, used as a proxy for Azerbaijan based on data vintage

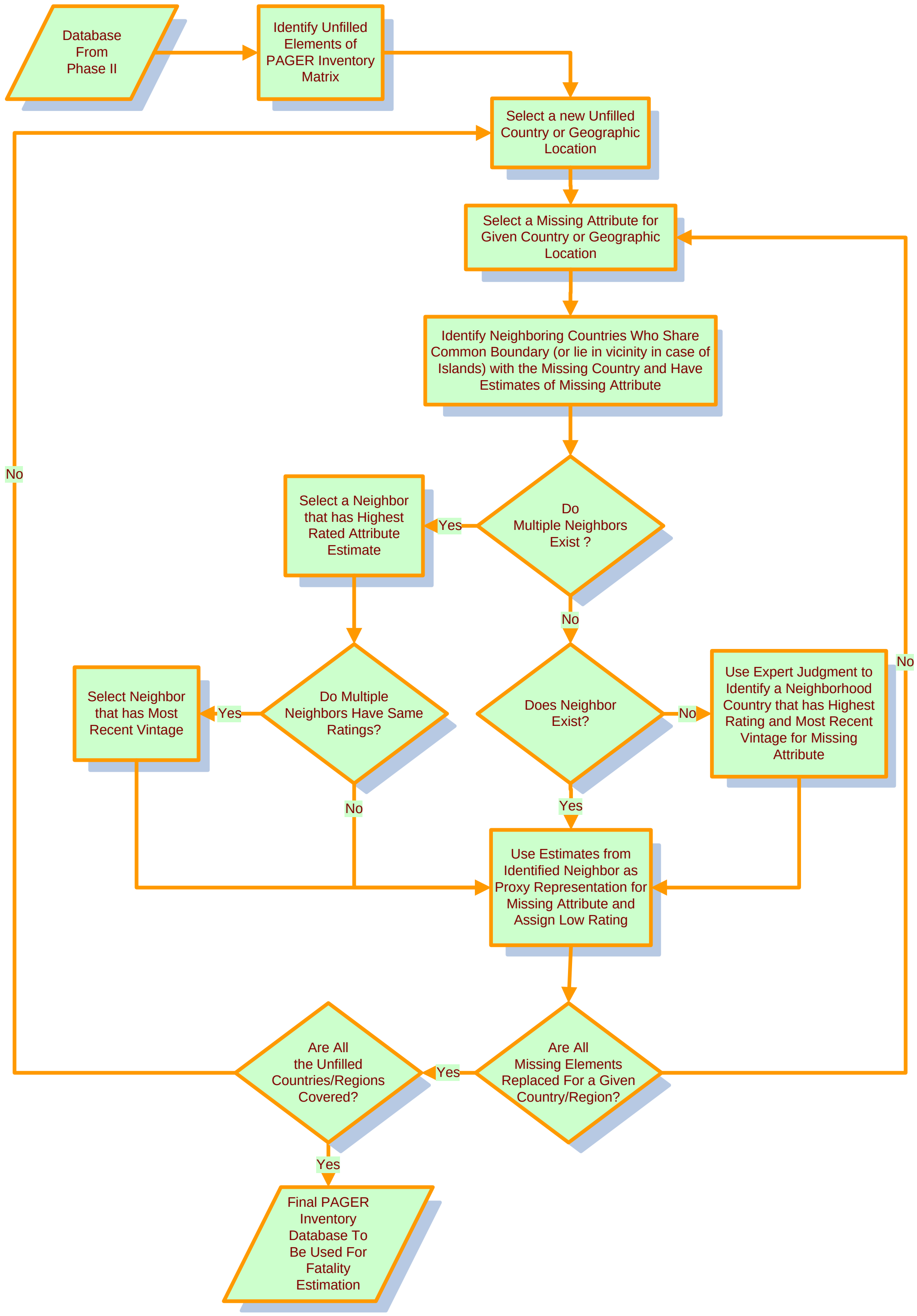


Figure 9. Schematic flowchart of the PAGER inventory development methodology (Phase III – Filling the missing elements)

Figure 10. Photograph showing typical rural house in Bangladesh made of straw, mud, and timber frame

Figure 11. Photograph showing general housing stock in Thailand (Bangkok) obtained from general Internet search

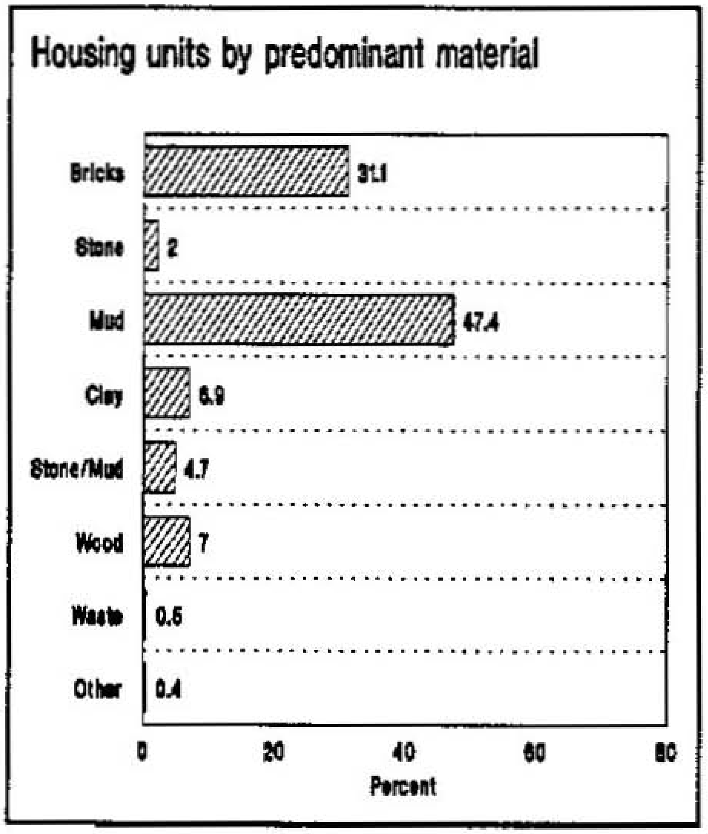


Figure 12. Bar chart showing housing stock distribution for Peru (United Nations, 1993)

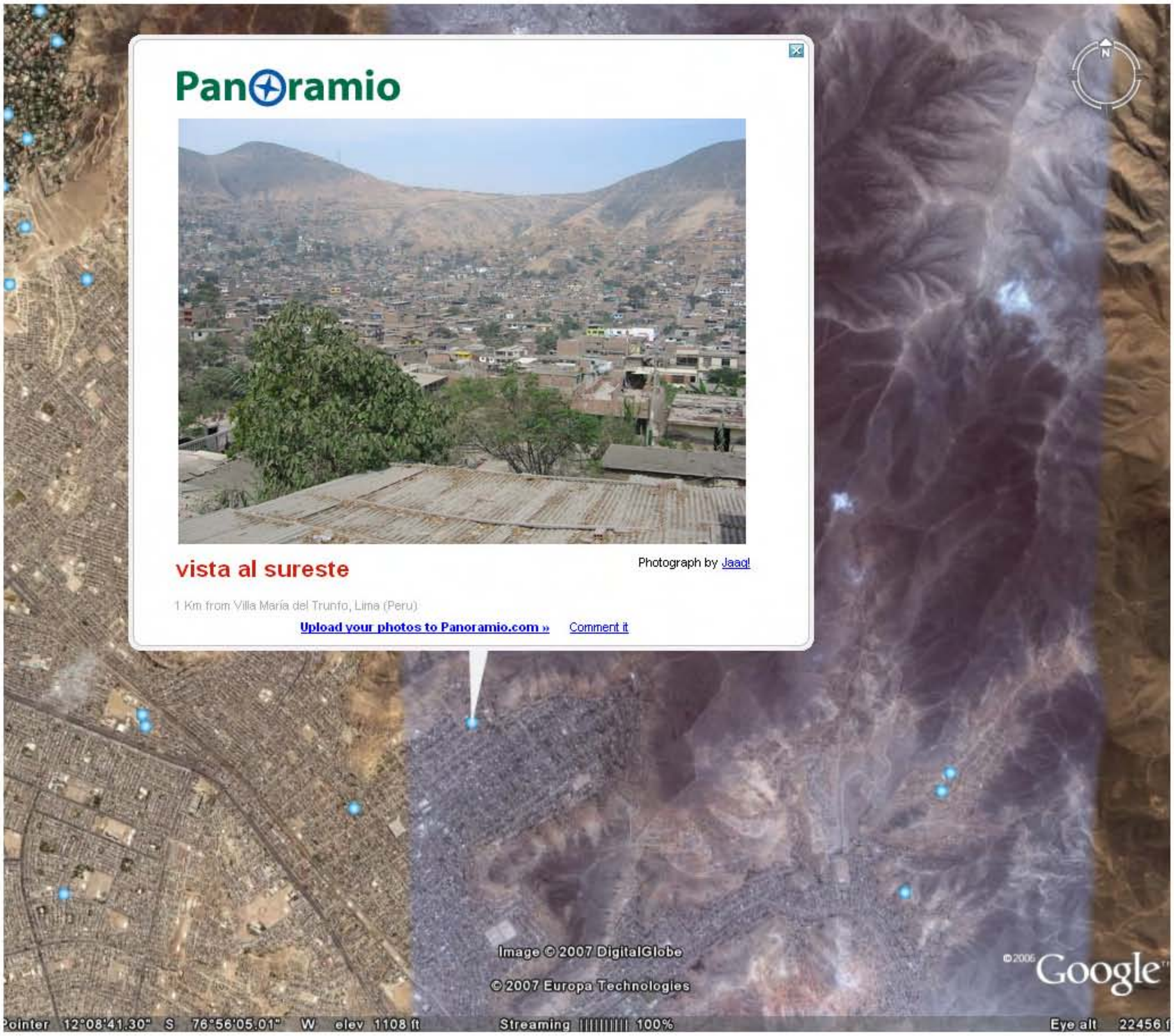


Figure 13. Photograph showing typical residential building stock in Peru constructed using brick masonry construction

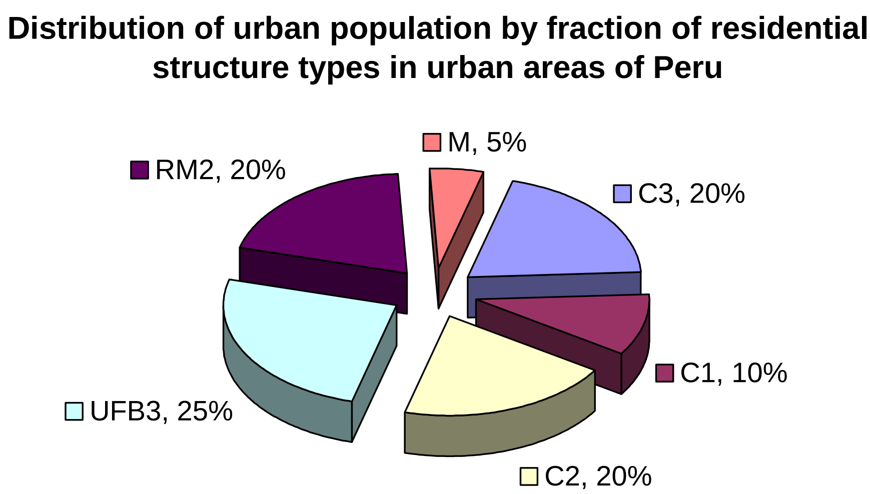
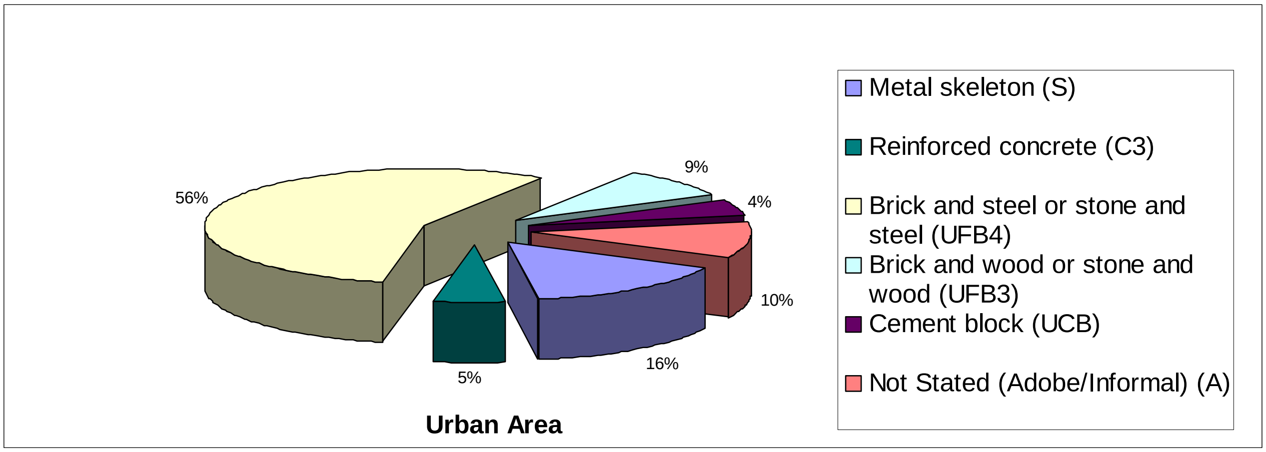


Figure 14. Pie chart showing distribution of housing stock in urban areas of Peru obtained from WHE-PAGER expert survey



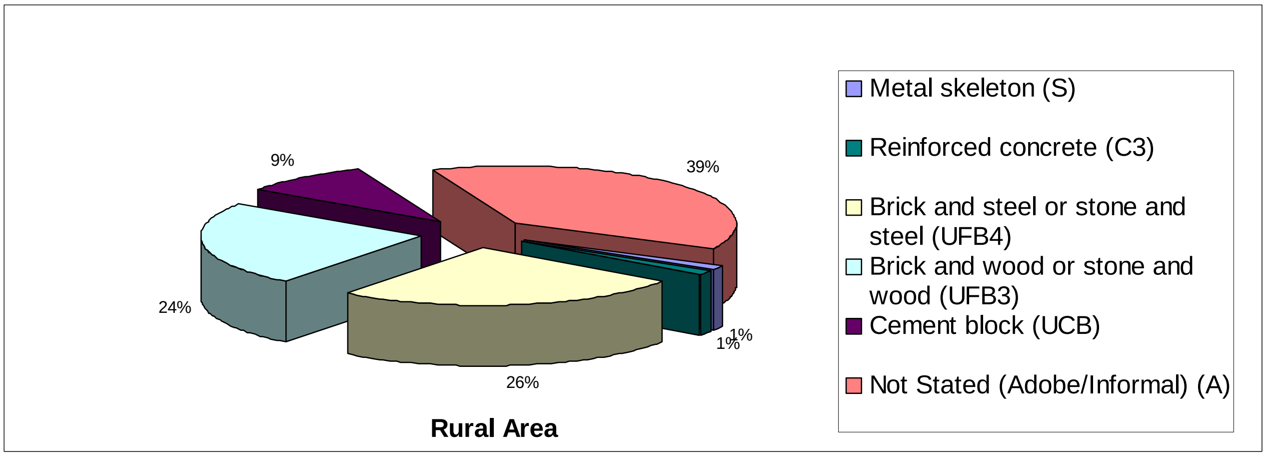


Figure 15. Pie chart showing distribution of housing stock in urban and rural areas of Iran obtained from housing census data (Iran Statistical Year Book, 2005)

Figure 16. Photograph showing typical multistoried reinforced concrete apartment buildings with masonry infill walls in Ankara, Turkey

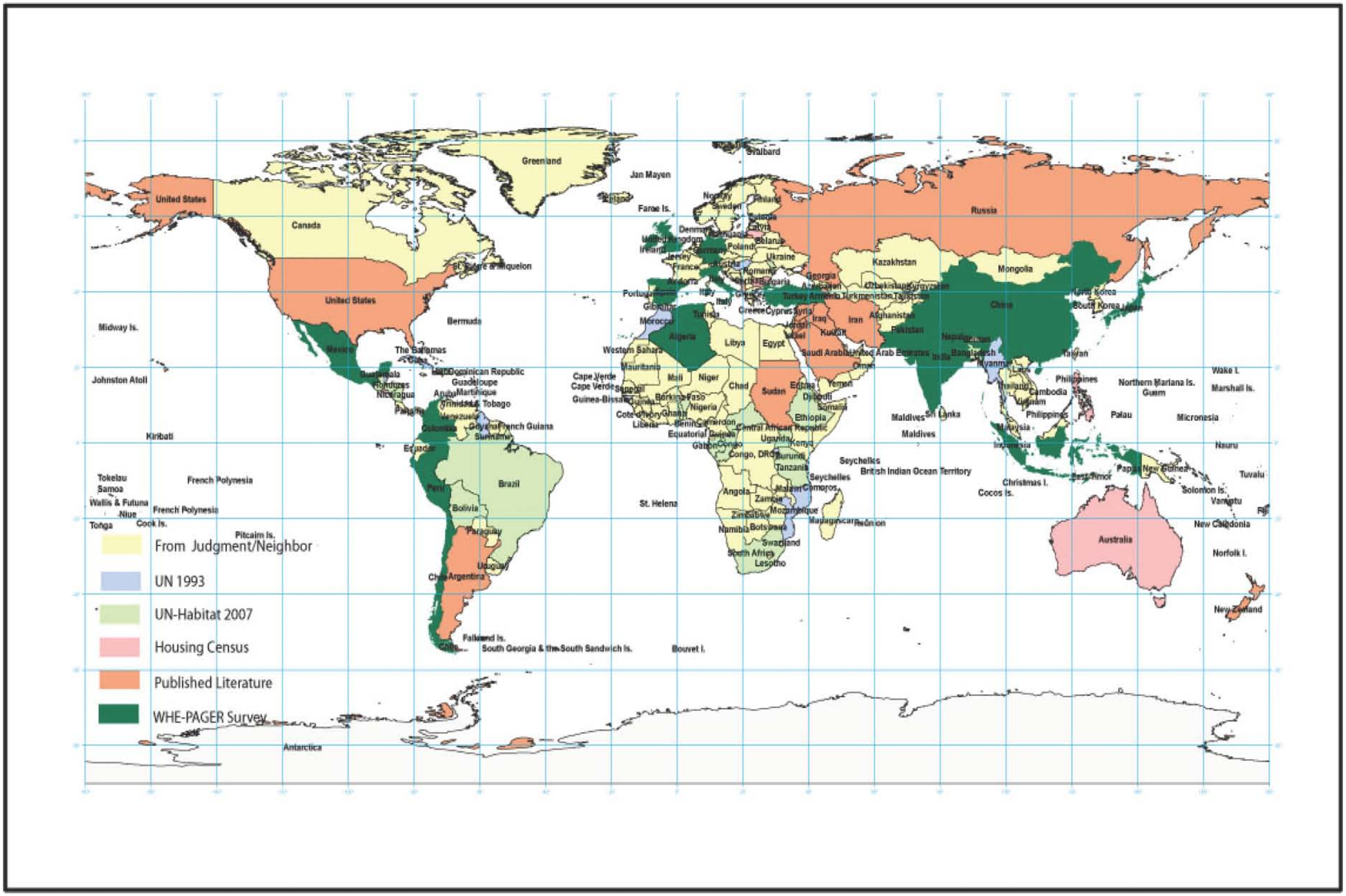


Figure 17. Map showing global coverage of PAGER building inventory database with data compiled from various sources