FINAL TECHNICAL REPORT

PROVIDING BUILDING DATA IN SUPPORT OF PAGER

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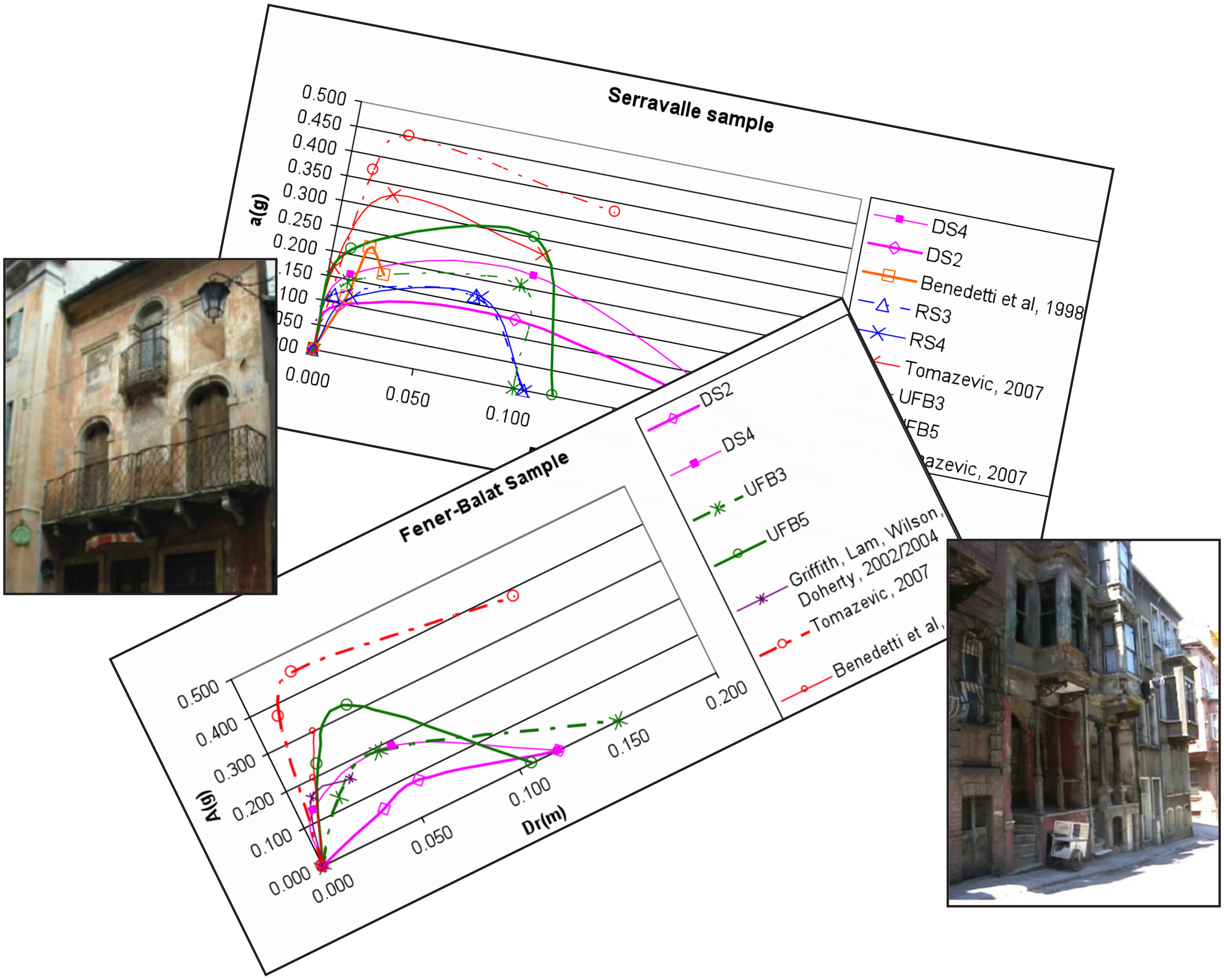

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FINAL TECHNICAL REPORT

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Abstract:

The EERI World Housing Encyclopedia (WHE)-USGS PAGER project is an initiative to improve the understanding and classification of building inventory and collapse vulnerability of non-U.S. construction types worldwide. Phase III of this project, completed in 2009, was a collaborative effort among EERI staff, volunteers participating through EERI's World Housing Encyclopedia and USGS PAGER model developers. Work in this phase focused on identifying capacity curves and fragility functions for the most common of these building types, organized by construction material: brick masonry, concrete, timber, adobe and mud, stone masonry and concrete block. This phase of work has built on previous work where volunteers identified building collapse fragility functions based on empirical, intensity-based data. Modifications were made in the procedures to collect these empirical data, including revising the structure types, modifying the definition of collapse and dropping PGA in favor of intensity, as well as then focusing on collecting analytically--based damage functions for major non-U.S. construction types. This Technical Report describes this progress in more detail.

Table of Contents

(presentations from workshop are available at http://pager.world-housing.net/background-papers-2/presentations-from-sept-09-workshop)

FINAL TECHNICAL REPORT:
Providing Building Data in Support of PAGER

BACKGROUND

The EERI World Housing Encyclopedia (WHE)-USGS PAGER project is a collaborative initiative to improve the understanding and classification of building inventory and collapse vulnerability of non-U.S. construction types worldwide. The assessment of building stock vulnerability is directly helping the USGS PAGER semi-empirical and analytical loss models to reliably estimate the casualties in the near-immediate aftermath of any destructive earthquake worldwide. The work described below has been completed in 2009 by a collaborative effort among EERI staff, volunteers participating through EERI's World Housing Encyclopedia and USGS PAGER model developers. See Appendix A for the Project Steering Committee.

In order to provide accurate, rapid estimates of damage and casualties, the PAGER model needs to incorporate a clear understanding of the performance of major non-U.S. or less-engineered construction types. Work in Phase III of the collaboration between WHE and PAGER is identifying capacity curves and fragility functions for 25 of the most common of these building types, organized by construction material: brick masonry, concrete, timber, adobe and mud, stone masonry and concrete block.

The collaboration described here between the U.S. Geological Survey's (USGS) Prompt Assessment of Global Earthquakes for Response (PAGER) project and the Earthquake Engineering Research Institute's (EERI) managed online World Housing Encyclopedia has been ongoing for the past two years. The objective of this joint effort is to mobilize the expertise within the WHE community to provide reliable estimates of the collapse fragility of the building stock by structure and occupancy type at a national level. These data then feed into the PAGER database to produce prompt assessment of earthquake casualties in the immediate aftermath of an earthquake with a magnitude greater than 5.5, on a worldwide basis. The ultimate aim of this project is to provide robust information on damage and casualties, primarily for response efforts, but also for mitigation purposes. The WHE-PAGER collaboration consists of several phases as outlined in Table 1. These phases have progressed from the identification of building collapse fragility functions based on empirical, intensity-based data, to analytically--based damage functions for major non-U.S. construction types. This Technical Report describes progress in Phase III.

Table 1: Summary of WHE-PAGER Phases of Work

PHASE	SUMMARY OF WORK	TIME FRAME
Phase I	Expert opinion (empirical model) from individual countries, estimating vulnerability & inventory	April-December 2007
Phase II	Workshop of international experts to decide on analytical approach. Experts then provided data for some major non-US construction classes.	May 2008—December 2008
Phase III	Based on expert evaluation of the data provided in Phase I at the May 2008 workshop, significant improvements were made to the forms and instructions used to solicit expert opinion (the empirical model). Experts were given a chance to revise their opinions and experts from new countries were recruited, to round out this phase of the PAGER model. Critically important non-HAZUS building typologies and the compilation of respective capacity curves and fragility functions within the analytical framework of HAZUS-MH were developed A small workshop was held in September 2009 to share and discuss results.	January-December 2009
Phase IV [2010 grant]	Comparison of global models to define capacity and fragility curves--with objectives to optimize and generalize the number of parameters needed to obtain reliable curves in presence of modest data; and to identify, quantify and reduce uncertainties on values obtained, for application worldwide. Models will be tested by comparing with historic and recent earthquake performance data, and by comparing with results from the PAGER empirical approach.	January-December 2010

The major milestones achieved so far can be summarized as follows:

- During Phase I of the project, WHE experts supported the empirical approach by providing, on a country basis, inventory data of predominant buildings typologies and intensity-based building collapse fragility functions for 26 different countries. See Appendix B for a listing of reports available.
- These Phase I results were then analyzed and the Phase I approach modified to obtain data for additional countries. The analysis and modifications included:
  - the identification of problematic data,
  - an updated and more complete taxonomy of building typologies,
  - a new (updated) protocol/questionnaire for the collection of (fragility) data,
  - a new definition of damage states,
  - a new framework for the definition of collapse rates influencing casualty rates,

    - modification of the data collection process to facilitate a second round of expert opinion solicitation for a new set of countries.
- During Phase II and Phase III, critically important non-HAZUS building typologies were identified and respective capacity curves and fragility functions were collected within the analytical framework of performance-based assessment, constituting the analytical model of the PAGER project. Several tasks were required in order to accomplish this work including: clarification of the definition of collapse; updating the building class definitions; correlating vulnerability with measures of shaking; and explaining the meaning and validation of a performance-based approach for non-engineered building types. These tasks are discussed below.

It should also be noted here that the project has now entered a Phase IV, since it has become apparent to project participants that there is yet one more missing piece in understanding how to incorporate knowledge of major non-U.S. construction types into PAGER. This missing piece is the realization, made clear in Phases II and III of this work, that by using different procedures to define capacity curves for similar structure types, very different answers can result. To date, when comparing model results to recent earthquake damage, the empirical model is predicting casualties more accurately than the analytical model. To increase the reliability and robustness of PAGER by improving the predictive capabilities of the analytical model and to better understand uncertainties associated with PAGER, we now need a better understanding of the range of possible curves that result from several global models addressing similar non-U.S. or less engineered construction types. Phase IV work in calendar year 2010 will address these issues, and make recommendations to the PAGER model developers.

TASKS COMPLETED IN PHASE III WORK: PROVIDING BUILDING DATA IN SUPPORT OF PAGER

Empirical Collapse Fragility

In the initial phase of development of the empirical intensity-based model, experts provided distribution and occupancy of predominant building types and their fragility functions for 30+ countries. Efforts were first focused on countries with substantial seismic risk. In many cases the inventory judgments were informed by local housing censuses and other public data sources. The methodology, results and analysis of the Phase I survey data along with the original contributions from experts for each country are documented in Jaiswal & Wald (2009), Porter et al. (2008), and the procedure adopted for compilation of such datasets is described through country-specific experiences by Goretti et al. (2008) and Pomonis et al (2009). In addition, the data are all available online, at the WHE-PAGER website developed as part of this project (www.pager.worldhousing.net).

The vulnerability definition in this phase was limited to the collapse probability for each structure type, given a specified shaking level. Structure types were assigned with the WHE construction classes (see http://www.world-housing.net/) and the shaking intensity levels were expressed in modified Mercalli intensity (MMI) as well as peak ground acceleration (PGA). Results have been analyzed for similar structure types and were compared in terms of vulnerability curves among different countries.

Expert feedback and data review led to an update of the data collection method, which ensured better consistency from country to country and limited the need for data post-processing. As the collection of empirically based data was rolled out to more nations worldwide modifications were introduced to address these shortcomings. See Appendix C for the revised data collection form.

New Structural Types Catalogue (PAGER-STR)

It became apparent early in this project work that the catalogue of WHE construction types was insufficient to cover all entries, and that many of the experts were describing building types that had relevance beyond their own countries. Moreover, the descriptions provided in the WHE construction type catalogue do not always unequivocally indicate the specific characteristics that define seismic vulnerability or resilience of a given typology. PAGER staff conducted a comparative study of construction typology catalogues available in the literature relevant to the PAGER aims. Specific sources included ATC (1985), HAZUS-MH (FEMA 2003), EMS-98 (Grünthal 1998), and Coburn and Spence (2002). A new catalogue was developed, structured logically from very generic broad building types, applicable when no detailed information is available, to specific subcategories, able to identify a type and its seismic behavior unequivocally. Currently the PAGER-STR has in excess of 100 structures types, and is organized in two description tiers, where each subcategory is identified by a succinct description of the vertical structure providing earthquake resistance, the type of horizontal structure, and the height of the building (Jaiswal and Wald, in progress). Some other parameters that can influence vulnerability, such as year of construction (which can be a proxy for code compliance) are applied as modifying factors to the reference fragility curve. The PAGER-STR is validated by mapping all typologies that were submitted by experts, and by ensuring that buildings from different countries with similar structure types and comparable vulnerabilities fell into the same PAGER-STR categories and sub-categories (Jaiswal and Wald 2009). The description for each building subcategory is specific enough so that there is little ambiguity in class assignment. The list, available at the WHE-PAGER project website (http://pager.world-housing.net/data-available/construction-types), is not exhaustive. (The current list is also included here as Appendix D.) It will be revised as data from new countries with different construction technologies are contributed and further refinements of the descriptions are also possible. Given its open logic tree structure, subcategories can be introduced where particular seismic relevant construction details emerge that directly affect the fragility of a regional type. A further validation of the PAGER-STR catalogue was performed by using these classes as reference for the first trial development of the analytical data discussed below.

PGA and Macroseismic Intensity Ranges

An issue that emerged from the experts' feedback during Phases I and II is the perceived limited validity of the correlation between MMI intensity levels and PGA from a global viewpoint, as it was originally presented in the survey form. As several empirical correlation curves exist for the conversion of PGA to intensity this suggests that either regional difference for these correlations exist, or these correlations are based on limited data ranges within each region, compounded perhaps by variable intensities assignments. Worldwide there is little direct evidence for the correlation between the level of damage, or probability of collapse, and the PGA. Therefore, the PGA ranges were removed in favor of a correlation table with the most common macroseismic intensity scales such as MMI, European Macroseismic Scale (EMS) and Medvediav Sponheur Karnik (MSK) scale. Most published analyses suggest that these scales are very similar in the range of most interest to this project, between the degrees of VI and IX. Experts can indicate the intensity scale that is relevant to their collapse probability assessment.

Definition of Collapse and Collapse Probability Ranges

The definition of collapse in earthquake engineering is dependent on the nature of the structure, the scope of the study and the method of analysis used in the study. A more comprehensive review of definitions of collapse that are commonly used in literature and their implication for the computation of casualty probability curves is provided in Jaiswal et al. (in prep). In the initial phase of the WHE-PAGER project, the definition of collapse that is used in HAZUS-MH was offered to the experts as a source of reference. HAZUS-MH provides a procedure to estimate the collapse percentage of the total square footage of a structure type using a complete damage state fragility curve and a factor Pc, where Pc represents the fraction of building area that collapses among structures that have experienced the complete structural damage state (FEMA 2003).

In EMS-98 the collapse state is associated with specific damage grades and with each shaking intensity level, to provide he probability of a particular vulnerability class experiencing the damage state of collapse. The EMS-98 collapse definition is limited to European observations and is applicable specifically to the European building stock; however, the consistency among EMS-98, MSK, and MMI, make such definitions sufficiently general to be applicable for the scope of the empirical Intensity-based model of the WHE-PAGER project at a global scale. In order to clarify what is intended by collapse in this context, specifically associated with casualties, definitions were proposed for each structural typology, focusing on those building elements whose failure leads to partial or total collapse of the building (and thus casualties). EMS-98 provides collapse probability ranges for a given vulnerability class for each level of intensity. Although EMS-98 groups structures of different typologies into the same vulnerability classes, it is possible to disaggregate such definitions and assign collapse rates to each structure type for a given intensity. This was done for each PAGER–STR tier 1 generic classes, predefining the expected proportion of collapses estimated using structure-dependent descriptions of damage within EMS intensity scale. These ranges can be used as guidance by experts completing the survey for the empirical intensity-based model to understand the expected behavior of structure types pertaining to the same PAGER-STR class. See Table 2. This is particularly relevant in countries where there is limited evidence of damage due to past earthquakes, yet the building stock has substantial vulnerability.

Table 2. Expected range of collapse probability (combination of EMS-98 Grade 4 and 5 damage states) as a function of EMS shaking intensities for various structure type

Structure Type	EMS Class	EMS Most Likely Vul. Class	Probability of Collapse at Intensity			
			VI	VII	VIII	IX
Rubble stone, field stone	M1	A	0 %	0 to 5 %	2.5 to 32 %	21.25 to 70 %
Adobe (earth brick)	M2	A	0 %	0 to 3.8 %	1.9 to 25 %	17 to 61 %
Simple stone (dressed)	M3	B	0 %	0 to 0.3 %	0.13 to 6.5 %	3.5 to 34 %
Massive stone	M4	C	0 %	0 %	0 to 1.3 %	0.6 to 12 %
Unreinforced brick	M5	B	0 %	0 to 0.3 %	0.13 to 6.1 %	3.3 to 33 %
Unreinforced brick with RC floor	M6	C	0 %	0 %	0 to 1.3 %	0.6 to 12 %
Reinforced or confined masonry (assuming 5 % in B, 50 % in C and 45 % in D)	M7	D	0 %	0 %	0 to 0.3 %	0.1 to 4 %
Reinforced concrete frame without ERD	RC1	C	0 %	0 to 0.3 %	0.13 to 2.6 %	1.6 to 13.4 %
Reinforced concrete frame with moderate ERD	RC2	D	0 %	0 %	0 to 0.25 %	0.15 to 2.6 %
Reinforced concrete frame with high ERD	RC3	E	0 %	0 %	0 %	0 to 0.25 %
Reinforced concrete shear walls without ERD	RC4	C	0 %	0 %	0 to 0.25 %	0.13 to 5.1 %
Reinforced concrete shear walls with moderate ERD	RC5	D	0 %	0 %	0 %	0 to 0.25 %
Reinforced concrete shear walls with high ERD	RC6	E	0 %	0 %	0 %	0 %
Steel frame (all type)	S	E	0 %	0 %	0 to 0.5 %	0.25 to 4.5 %
Timber structures (all type as per EMS 98)	W	D	0 %	0 %	0 to 0.25 %	0.13 to 2.6 %
Timber structures (high ERD)	WA	-	0 %	0 %	0 %	0 %
Timber structures (medium ERD)	WB	-	0 %	0 %	0 to 0.25 %	0.13 to 2.6 %
Timber structures (low ERD)	WC	-	0 %	0 to 0.3 %	0.13 to 5 %	3 to 27 %

Analytical Model Based on Push-Over Analysis

The approach chosen for the development of the analytical model in the PAGER project refers to the framework developed within HAZUS-MH. This choice raises some issues when dealing with losses at a global level. The first issue is that while the HAZUS methodology is well--documented, the approach for establishing empirically founded vulnerability parameters is not well--established. The calculation of structural response and loss can require an iterative solution. This has made it challenging to produce vulnerability functions for structure types that are not included in the HAZUS-MH catalogue. Furthermore the development of capacity and fragility curves for a given typology can require a large number of parameter values, some of which it has been argued are strictly related to the behavior of engineered structures and may not be readily available or relevant for other non-U.S. structure types. This problem of a non-iterative solution has been discussed at length and an analytical solution proposed by Porter (2009).

In order to provide accurate, rapid estimates of damage and casualties, the PAGER model should also represent the performance of major non-U.S. or less-engineered construction types. Work during this project year has been aimed at identifying capacity curves and fragility functions for 25 of the most recurrent and critical of these types. The curves are divided by construction material: brick, stone and concrete block masonry, concrete frames, concrete frame and shear wall systems and confined masonry, timber, adobe and mud. Experts contributed the push-over capacity curves and fragility curves, either by analysis of existing experimental results or by use of numerical procedures. See Appendix E for the data input form that volunteers used.

In delivering this work, validation is required to extend the results obtained by numerical approaches to similar structure types in other regions, and to extend experimentally derived pushover curves to large sets of buildings. This validation ensures the reliability of the PAGER estimates of building damage and associated casualties, particularly in countries where construction is non- or marginally-engineered, and where the construction materials and technologies are not well-documented (low-engineered concrete structures, and various subtypes of brick and stone masonry). The strategy adopted for this phase of the project includes: a) literature survey of existing proposed representative push over curves for given building types from either experimental or analytical models developed by established researchers; b) compilation of tests details, representativeness of models, obtained results, etc and similarly for the analytical procedures (methodology, range of parameters considered, type of analysis, type of results); c) by use of selected specific procedure/s delivery of analytical pushover curves on the basis of data already available and region specific; d) comparison of derived curves with relevant present in literature; e) derivation of mean and standard deviation of the collapse capacities for generating the collapse fragility curves for given building types.

To date results have been obtained for 14 of the 25 initially identified buildings types covered: various types of stone masonry, from rubble to massive, set in different types of binder and with flexible or stiff horizontal structures; various type of brick masonry; confined masonry; ductile and non ductile reinforced concrete frames with and without masonry infills; dual systems of concrete frames and shear walls. These building types were representative of wide geographic coverage: North India, Nepal, Italy, Greece and the south Mediterranean, Turkey, Chile, Mexico and Peru. Data are limited for non-HAZUS timber structures types, for adobe structures, for steel moment frame and steel frames with masonry infills, and for precast reinforced concrete moment resisting frame with masonry infill walls. Table 3 provides a summary of the structural types and regions covered so far.

Table 3. Summary of analytical phase contributions

Country/Region	Structure Type	Description/Coverage	Contributors
Turkey	Mid-rise reinforced concrete frame	Urban building stock of Turkey	P. Gulkan and A. Yakut (1 type)
Peru	Confined masonry	Typical two story dwelling in coastal cities of Peru	A. Munoz (1 type)
Mexico	Reinforced masonry. Confined masonry with hollow/solid blocks. Unreinforced fired brick masonry	Mexican building stock.	R. Meli (4 type)
Northern India	Unreinforced fired brick masonry with RC lintel band	North India, modern brick building construction following Indian Standard IS4326	D. Rai (1Type)
Slovenia/ Mediterranean	Unreinforced fired bricks, dressed stone masonry, confined masonry	Experimental shaking table results	M. Tomazevic and M. Lutman (3 types)
Italy/Southern Europe	Unreinforced fired brick, dressed stone, massive stone, rubble stone masonry	Historic buildings in Turkey, Italy, Middle East, 2 to 4 storey high	D. D'Ayala & K. Collins (24 types)
Greece	Ductile and non-ductile reinforced concrete frame with or without infill Reinforced concrete-dual frame	Low, mid and high rise with low and high code construction. No infill, full infill, and soft story types	A. Kappos and G. Panagopoulos (total 5+18 types)
India	Unreinforced fired brick masonry	Various types of binder and floor structure 1 to 2 storey	D. Lang and Y. Singh (total 6 types)
India	Non-ductile reinforced concrete frame with or without infill.	Typical 4storey full infill and soft storey. Modern construction in North-India.	H. Kaushik (total 5 types)
South America	Confined masonry with concrete block/brick	Mexico, Peru and Chile. One, two and four story.	A Lang & GM Benzoni (24 types)

Validity of Curves Extracted from Experimental or Analytical Work Published by Others

For non engineered structures and structures that are not directly compliant to a seismic code in a specific region, the availability of experimental tests aimed at characterizing the seismic resilience of that structure type might be a valuable resource in producing a representative push-over curve to be used in a casualty loss analytical model. Specifically, shaking table tests were singled out as potentially very useful to this end. Tests results were collected for adobe structures (e.g., by McGowan 2009), stone and brickwork masonry structures, and confined masonry, concentrating on cases were 3D models of entire structures had been tested, rather than single structural components. Even in cases where results were presented directly in the form of push over curves, several issues arose, primarily related to the scale of the test, the amount and completeness of information published, the scope of the test, the geographic and typological validity of the results. One very important issue is whether the tests had been actually performed to complete or partial collapse, or only to some extent beyond the post peak capacity point to validate given ductility assumptions. In the latter case it is not possible to define ultimate conditions and associated casualty rates. A second issue relates to the applicability of a series of tests to a particular section of the building stock and how can this be treated from a stochastic point of view. In other words whether the tests results should be considered as representative of an average or a limit behavior, whether the tests campaign had sufficient repetition that scatter and standard deviations could be computed, and whether such figures are applicable to the fragility curve representative of the whole building stock for the region of interest.

Website

A website has been developed for the project that contains all the materials developed for the first phases of the project, including the empirical data, data that were provided as a result of the May 2008 San Francisco workshop and analytical data provided during the current phase described here. The URL is http://pager.world-housing.net/.

Workshop

In conjunction with another EERI workshop, a one-day workshop with several of the PAGER participants was held in September 2009. This workshop allowed some of the core project participants to share their approaches and some of their data. Appendix F contains the list of participants, and Appendix G is the workshop agenda. The presentations from the workshop are available at the project website at http://pager.world-housing.net/background-papers-2/presentations-from-sept-09-workshop.

Conclusions

Empirical and analytical collapse fragility data have been compiled under the auspices of the WHE-PAGER project and some preliminary analysis conducted. The project has been implemented by international engineering experts from more than thirty countries, volunteering through EERI's World Housing Encyclopedia project. As discussed above, this project has been conducted in several phases, and adaptations have been made as the project progresses through these phases. Such adaptations include modifying the list of structural types, modifying the input shaking hazard in terms of shaking intensity, defining collapse and providing improved guidance to experts in conducting future surveys. The comparative analysis for selected building type indicated that except for a few countries, most contributions were within the acceptable range of the EMS-based collapse vulnerability limits. The pushover curves obtained within the analytical framework showed a large spread in terms of yield and ultimate points; however some of the spread is expected given the potentially large variations in building design and construction practices within the same structure type from country to country and even within a country (rural vs. urban; pre or post code or level of building code enforcement). The next phase will continue to develop analytical curves for missing structure types, and will also provide an opportunity to test procedures other than HAZUS-MH to estimate these curves. The hope is that this project will lead to a better understanding of the collapse vulnerability of buildings worldwide and most importantly will improve the mechanisms for sharing knowledge and data-among the global research community.

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PROJECT STEERING COMMITTEE

The steering committee for this project is composed of engineers and architects who are world leaders in the testing and performance of various construction materials including stone and brick masonry, RC frames with infills, confined masonry, and adobe, as well as risk and vulnerability assessments. They have done testing at laboratories in Europe (Italy, Greece, Slovenia, Turkey, U.K.), Latin America (Mexico, Peru), South Asia (India) and New Zealand. Several of them are participating in the development of other risk and vulnerability models (including such projects as GEM, SELENA, FaMIVE, DRAin3dx, LESS-LOSS, SAVE, ENSeRVES, STEP, and RISK-EU) and thus are very familiar with the issues in developing engineering parameters for non-U.S. construction. In addition, they are prominent leaders in this field so can call on additional colleagues to participate in this effort. Two of the members of the steering committee, Roberto Meli and Polat Gulkan, have been or are on the Board of the International Association for Earthquake Engineering (IAEE).

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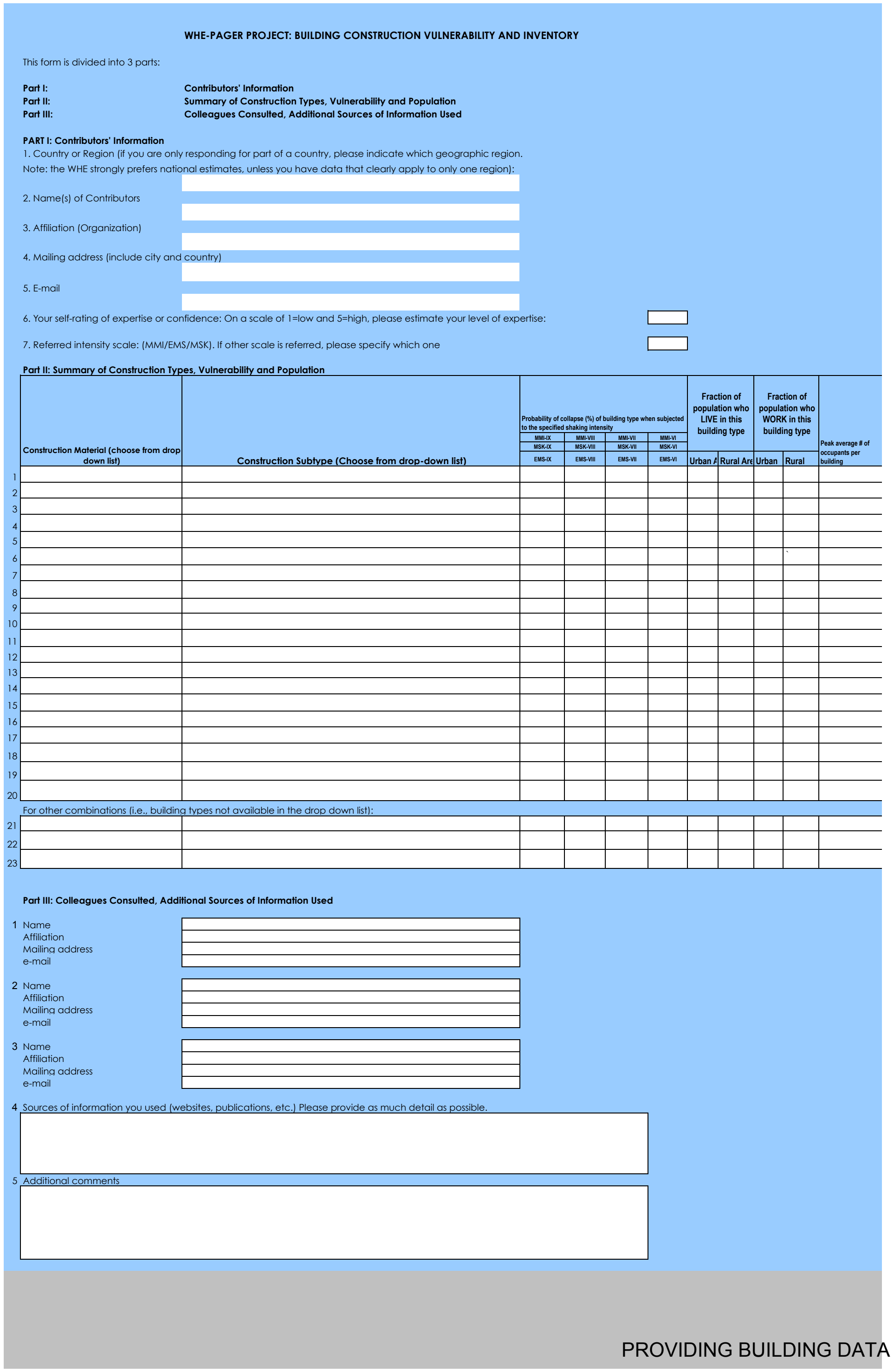


WHE-PAGER PROJECT: BUILDING CONSTRUCTION VULNERABILITY AND INVENTORY

This form is divided into 3 parts:

Part I:	**Contributors' Information**
Part II:	**Summary of Construction Types, Vulnerability and Population**
Part III:	**Colleagues Consulted, Additional Sources of Information Used**

PART I: Contributors' Information

1. Country or Region (if you are only responding for part of a country, please indicate which geographic region.
Note: the WHE strongly prefers national estimates, unless you have data that clearly apply to only one region):

2. Name(s) of Contributors

3. Affiliation (Organization)

4. Mailing address (include city and country)

5. E-mail

6. Your self-rating of expertise or confidence: On a scale of 1=low and 5=high, please estimate your level of expertise:

7. Referred intensity scale: (MMI/EMS/MSK). If other scale is referred, please specify which one

Part II: Summary of Construction Types, Vulnerability and Population

	Construction Material (choose from drop down list)	Construction Subtype (Choose from drop-down list)	Probability of collapse (%) of building type when subjected to the specified shaking intensity				Fraction of population who LIVE in this building type		Fraction of population who WORK in this building type		Peak average # of occupants per building
			MMI-IX	MMI-VIII	MMI-VII	MMI-VI					
			MSK-IX	MSK-VIII	MSK-VII	MSK-VI					
			EMS-IX	EMS-VIII	EMS-VII	EMS-VI	Urban A	Rural Are	Urban	Rural	
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											

For other combinations (i.e., building types not available in the drop down list):

21											
22											
23											

Part III: Colleagues Consulted, Additional Sources of Information Used

1 Name
Affiliation
Mailing address
e-mail

2 Name
Affiliation
Mailing address
e-mail

3 Name
Affiliation
Mailing address
e-mail

4 Sources of information you used (websites, publications, etc.) Please provide as much detail as possible.

5 Additional comments

LISTING OF PAGER CONSTRUCTION TYPES AND COMPARISON OF CONSTRUCTION TYPES FROM VARIOUS SOURCES

Material	PAGER-STR	Description	HAZUS Class	WHE-EERI Class	EMS-98	Coburn & Spence 2002	Risk-EU
Wood/Timber	W	Wood			W		W
	W1	Wood stud-wall frame with plywood/gypsum board sheathing. Absence of masonry infill walls. Shear wall system consists of plywood or manufactured wood panels. Exterior is commonly cement plaster ("stucco"), wood or vinyl planks, or aluminum planks (in lower cost houses). In addition, brick masonry or stone is sometimes applied to the exterior as a non-load-bearing veneer. The roof and floor act as diaphragms to resist lateral loading. (US & Canadian single family homes).	W1	32		CT2	
	W2	Wood frame, heavy members (with area > 5000 sq. ft.) (US & Canadian commercial and industrial wood frame).	W2				
	W3	Light post and beam wood frame. The floors and roofs do not act as diaphragms. No bracing, poor seismic load resistance path with poor connections. Timber frame may have partial infill walls with or without timber cladding.		28			
	W4	Wooden panel or log construction. Walls are made of timber logs sawn horizontally in a square or circular cross section and assembled with special end joints. (Typically in central Asia, Russia).		33			
	W5	Walls with bamboo/light timber log/reed mesh and post (Wattle and Daub). (Wattle and Daub- a woven lattice/sticks of wooden strips called wattle is daubed with a sticky material usually made of some combination of wet soil, clay, sand, animal dung and straw).		30		AE2	
	W6	Unbraced heavy post and beam wood frame with mud or other infill material. Un-braced timber frame with connections meant to resist (gravity) vertical loads only. Floors or roof consists of wood purlins supporting thatched roof, wood planks or rafters supporting clay tiles.		29		CT1	
	W7	Braced wood frame with load-bearing infill wall system. Frame is diagonally braced and infill walls are generally made of brick masonry, adobe, or wooden planks or wattle & daub infill. (European style)		31			
Adobe/Mud Walls	M	Mud walls		3			
	M1	Mud walls without horizontal wood elements					
	M2	Mud walls with horizontal wood elements		4			
	A	Adobe blocks (unbaked sundried mud block) walls		5	M2	AA1	M2
	A1	Adobe block, mud mortar, wood roof and floors					
	A2	Adobe block, mud mortar, bamboo, straw, and thatch roof					

	A3	Adobe block, straw, and thatch roof cement-sand mortar					
	A4	Adobe block, mud mortar, reinforced concrete bond beam, cane and mud roof					
	A5	Adobe block, mud mortar, with bamboo or rope reinforcement					
	RE	Rammed Earth/Pneumatically impacted stabilized earth		6		AE1	
Stone/Block Masonry	RS	Rubble stone (field stone) masonry		1	M1		M1.1
	RS1	Local field stones dry stacked (no mortar) with timber floors, earth, or metal roof.		1			
	RS2	Local field stones with mud mortar.		1		AR1	
	RS3	Local field stones with lime mortar.				AR1	
	RS4	Local field stones with cement mortar, vaulted brick roof and floors					
	RS5	Local field stones with cement mortar and reinforced concrete bond beam.					
	DS	Rectangular cut-stone masonry block			M3	BD1	M1.2
	DS1	Rectangular cut stone masonry block with mud mortar, timber roof and floors					
	DS2	Rectangular cut stone masonry block with lime mortar					
	DS3	Rectangular cut stone masonry block with cement mortar					
	DS4	Rectangular cut stone masonry block with reinforced concrete floors and roof					
	MS	Massive stone masonry in lime or cement mortar		2	M4		M1.3
	UCB	Unreinforced concrete block masonry with lime or cement mortar		11	M5	BC1	
Brick Masonry	UFB	Unreinforced fired brick masonry			M5		
	UFB1	Unreinforced brick masonry in mud mortar without timber posts		7			
	UFB2	Unreinforced brick masonry in mud mortar with timber posts		8			M3.1
	UFB3	Unreinforced brick masonry in lime mortar					M3.2
	UFB4	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)				BB1	M3.3
	UFB5	Unreinforced fired brick masonry, cement mortar, but with reinforced concrete floor and roof slabs		9	M6		M3.4
Reinforced/Confi	RM	Reinforced masonry				DB1	M4
	RM1	Reinforced masonry bearing walls with wood or metal deck diaphragms					
	RM1L	Reinforced masonry bearing walls with wood or metal deck diaphragms low-rise	RM1L				
	RM1M	Reinforced masonry bearing walls with wood or metal deck diaphragms mid-rise (4+ stories)	RM1M				

	RM2	Reinforced masonry bearing walls with concrete diaphragms					
	RM2L	Reinforced masonry bearing walls with concrete diaphragms low-rise	RM2L				
	RM2M	Reinforced masonry bearing walls with concrete diaphragms mid-rise	RM2M				
	RM2H	Reinforced masonry bearing walls with concrete diaphragms high-rise	RM2H				
	RM3	Confined masonry		10	M7	BB2	M4
Reinforced Concrete	C	Reinforced concrete					
	C1	Ductile reinforced concrete moment frame with or without infill		15	RC3	DC1	RC1
	C1L	Ductile reinforced concrete moment frame with or without infill low-rise	C1L				
	C1M	Ductile reinforced concrete moment frame with or without infill mid-rise	C1M				
	C1H	Ductile reinforced concrete moment frame with or without infill high-rise	C1H				
	C2	Reinforced concrete shear walls		21	RC6		RC2
	C2L	Reinforced concrete shear walls low-rise	C2L				
	C2M	Reinforced concrete shear walls mid-rise	C2M				
	C2H	Reinforced concrete shear walls high-rise	C2H				
	C3	Nonductile reinforced concrete frame with masonry infill walls		16	RC2	DC2	
	C3L	Nonductile reinforced concrete frame with masonry infill walls low-rise	C3L				RC3
	C3M	Nonductile reinforced concrete frame with masonry infill walls mid-rise	C3M				
	C3H	Nonductile reinforced concrete frame with masonry infill walls high-rise	C3H				
	C4	Nonductile reinforced concrete frame without masonry infill walls		14	RC1	CC1	
	C4L	Nonductile reinforced concrete frame without masonry infill walls low-rise					
	C4M	Nonductile reinforced concrete frame without masonry infill walls mid-rise					
	C4H	Nonductile reinforced concrete frame without masonry infill walls high-rise					
	C5	Steel reinforced concrete (Steel members encased in reinforced concrete)				DH1	S5
	C5L	Steel reinforced concrete (Steel members encased in reinforced concrete) low-rise					
	C5M	Steel reinforced concrete (Steel members encased in reinforced concrete) mid-rise					
	C5H	Steel reinforced concrete (Steel members encased in reinforced concrete) high-rise					
	C6	Concrete moment resisting frame with shear wall - dual system		19		DC3	RC4
	C6L	Concrete moment resisting frame with shear wall - dual system low-rise					
	C6M	Concrete moment resisting frame with shear wall - dual system mid-rise					

	C6H	Concrete moment resisting frame with shear wall - dual system high-rise					
	C7	Flat slab structure		17			
Precast Concrete	PC1	Precast concrete tilt-up walls	PC1				RC5
	PC2	Precast concrete frames with concrete shear walls		18		DP2	RC6
	PC2L	Precast concrete frames with concrete shear walls low-rise	PC2L				
	PC2M	Precast concrete frames with concrete shear walls mid-rise	PC2M				
	PC2H	Precast concrete frames with concrete shear walls high-rise	PC2H				
	PC3	Precast reinforced concrete moment resisting frame with masonry infill walls				DP1	
	PC3L	Precast reinforced concrete moment resisting frame with masonry infill walls low-rise					
	PC3M	Precast reinforced concrete moment resisting frame with masonry infill walls mid-rise					
	PC3H	Precast reinforced concrete moment resisting frame with masonry infill walls high-rise					
	PC4	Precast panels (wall panel structure)		22		DP3	
Steel	S	Steel			S		
	S1	Steel moment frame		25		DS2	S1
	S1L	Steel moment frame low-rise	S1L				
	S1M	Steel moment frame mid-rise	S1M				
	S1H	Steel moment frame high-rise	S1H				
	S2	Steel braced frame		26		DS4	S2
	S2L	Steel braced frame low-rise	S2L				
	S2M	Steel braced frame mid-rise	S2M				
	S2H	Steel braced frame high-rise	S2H				
	S3	Steel light frame	S3			DS1	
	S4	Steel frame with cast-in-place concrete shear walls		24		DS5	S4
	S4L	Steel frame with cast-in-place concrete shear walls low-rise	S4L				
	S4M	Steel frame with cast-in-place concrete shear walls mid-rise	S4M				
	S4H	Steel frame with cast-in-place concrete shear walls high-rise	S4H				
	S5	Steel frame with unreinforced masonry infill walls		23		DS3	S3
	S5L	Steel frame with unreinforced masonry infill walls low-rise	S5L				
	S5M	Steel frame with unreinforced masonry infill walls mid-rise	S5M				
	S5H	Steel frame with unreinforced masonry infill walls high-rise	S5H				
Other	MH	Mobile homes	MH				
	INF	Informal constructions. (Generally made of wood/plastic sheets/GI Sheets/light					

		metal or composite etc not confirming to engineering standards, commonly in slums, squatters).					
	UNK	Not specified (unknown/default)					

WHE-PAGER PHASE 2: DEVELOPMENT OF ANALYTICAL SEISMIC VULNERABILITY FUNCTIONS

Author:
Date:
Structure type (describe as broadly as possible):
Geographic or other limitations:
Add rows as desired

Choice of pushover curve parameters

	Units	Parameter	
Pushover X-axis:			Choose spectral displacement (Sd); or Roof displacement (Deltar). State units
Pushover Y-axis:			Choose spectra acceleration (Sa); or base shear (V). State units.
Elastic damping ratio:			Small-amplitude damping ratio, fraction of critical
1st mode participation factor:			PFfR; generally 1.3 to 1.5; same as (effective height)/(total roof height)
Effective mass coefficient:			alpha1; generally 0.7 to 0.8
Building weight:			W State units

How were these values & pushover points derived?
Add rows as desired

Pushover Curve for this structure type

See Figures 1-4 for sample pushover curves

Pushover curve control point	X	Y	Damping	Comment	
A	0	0			Control point for plotting purposes
B					E.g., yield point?
C					E.g., ultimate point?
D					E.g., beginning of lower plateau?
E					Add rows as desired

Optional: upper and lower-bound range of pushover curves for this structure type

Upper-bound pushover curve, e.g., 99 out of 100 buildings of this type would have pushover curve inside the area bounded between this curve and the Y-axis?
Author's meaning of "upper bound":
How were these values & pushover points derived?
Add rows as desired

See Figures 1-4 for sample pushover curves

Optional upper-bound pushover curve

Pushover curve control point	X	Y	Damping	Comment	
A	0	0			Control point for plotting purposes
B					E.g., yield point?
C					E.g., ultimate point?
D					E.g., beginning of lower plateau?
E					Add rows as desired

Lower-bound pushover curve, e.g., 99 out of 100 buildings of this type would have pushover curve inside the area bounded between this curve and the X-axis?
Author's meaning of "lower bound":
How were these values & pushover points derived?
Add rows as desired

See Figures 1-4 for sample pushover curves

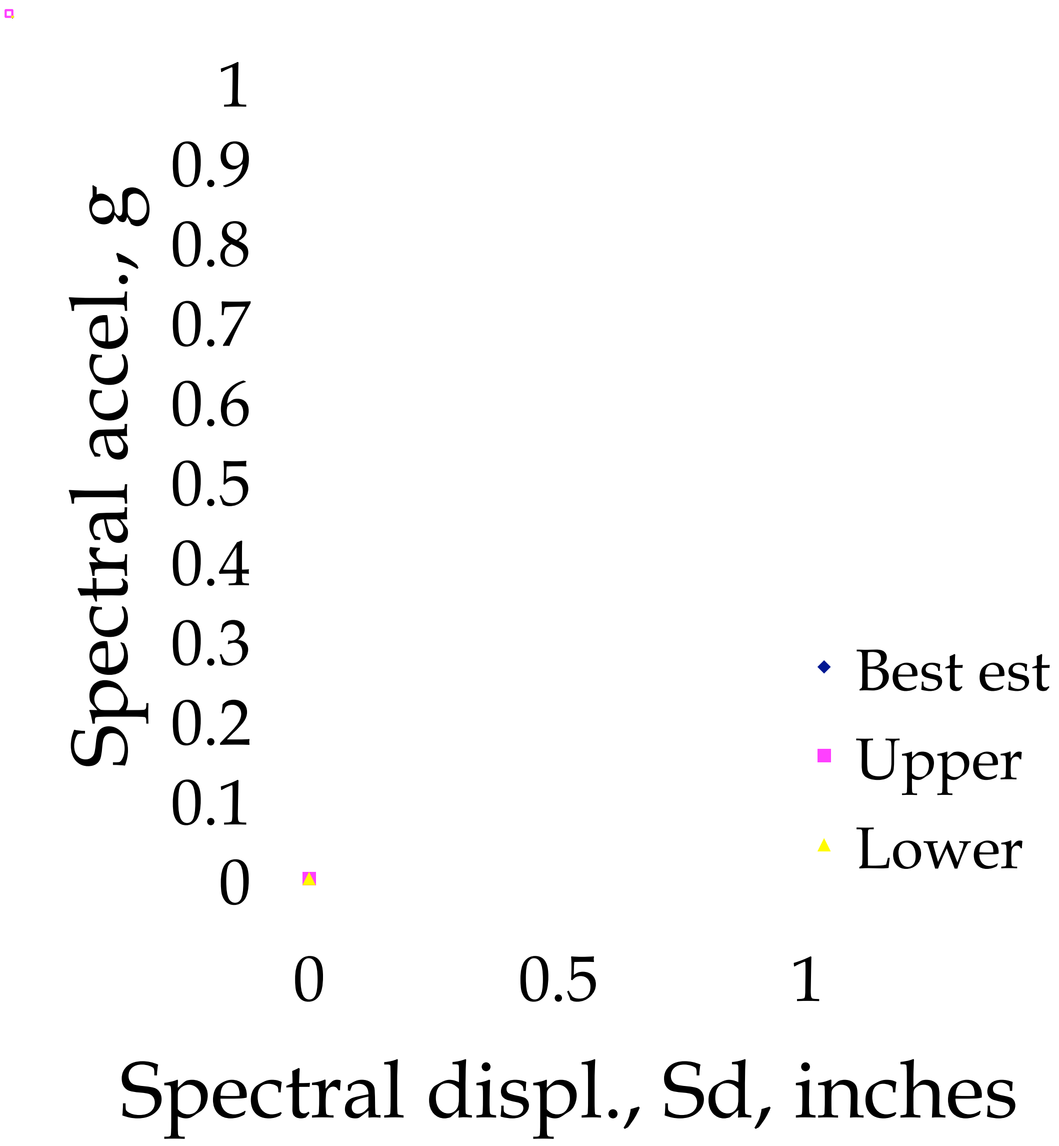
Optional lower-bound pushover curve

Pushover curve control point	X	Y	Damping	Comment	
A	0	0			Control point for plotting purposes
B					E.g., yield point?
C					E.g., ultimate point?
D					E.g., beginning of lower plateau?
E					Add rows as desired

Other requested parameters

D14		median drift (in same units as pushover X-axis) associated with complete structural damage, i.e., drift with 50% chance that the structural component of the building cannot be economically repaired
B14		logarithmic standard deviation of drift associated with complete structural damage. May need to be guessed
Sdc		the median value of drift (in same units as pushover X-axis) associated with collapse, e.g., Sdc = (roof drift at collapse)/PFfR.
L15		indoor fatality rate given collapse. Many contributors may be unable to provide this value. Porter, Comartin, and Holmes will fill such gaps
PC		mean fraction of building area collapsed, given complete structural damage. Again Porter, Comartin, and Holmes will fill gaps
kshort		If HAZUS-style damping preferred, and author can judge, this is the degradation factor for short-duration (M <= 5.5) events
kmed		If HAZUS-style damping preferred, and author can judge, this is the degradation factor for medium-duration (5.5 < M < 7.5) events
klong		If HAZUS-style damping preferred, and author can judge, this is the degradation factor for long-duration (M >= 7.5) events

Explain how these values were arrived at, providing citations if appropriate
Add rows as desired


Spectral accel., g
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
Spectral displ., Sd, inches
Best est
Upper
Lower

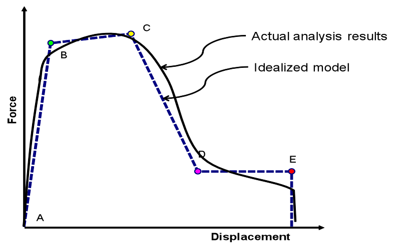


Figure 1: Force-displacement capacity boundary with all idealized segments present

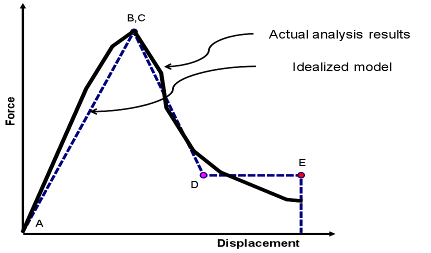


Figure 2: Force-displacement capacity boundary without strain hardening segment (e.g. buckling braced frame)

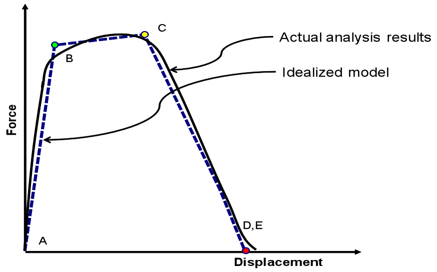


Figure 3: Force-displacement capacity boundary without lower strength plateau (e.g. unreinforced masonry)

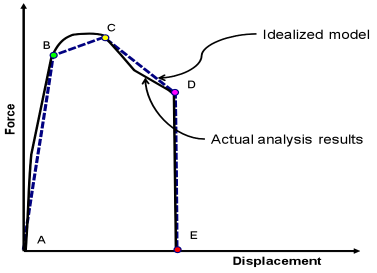


Figure 4: Force-displacement capacity boundary with pre-emptive vertical load failure

APPENDIX E

HAZUS PARAMETRS												VULNERABILITY PARAMETERS				STRUCTURAL IDENTIFICATION			APPROACH IDENTIFICATION		
Dy	Ay	Du	Au	BE	Kshort	kmed	Klong	I45	Teta14	Beta14	pc	Natual period	ductility factor	strength reduction factor	failure mode	vertical structure	horizontal structure	Pager structure type	Lit reference	analytical approach	procedure name

APPENDIX E

HAZUS PARAMETRS												VULNERABILITY PARAMETERS				STRUCTURAL IDENTIFICATION			APPROACH IDENTIFICATION			
Dy	Ay	Du	Au	BE	Kshort	kmed	Klong	I45	Teta14	Beta14	pc	Natual period	ductility factor	strength reduction factor	failure mode	vertical structure	horizontal structure	Pager structure type	Lit reference	test type	test charcteristics	

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EERI/WHE-PAGER Project Review Meeting
September 23, 2009
Preservation Park
Oakland, California

AGENDA

9:00 am	Introductions (All, 10 min)
9:10 am	Phases of WHE participation (Greene; 5 min)
9:15 am	Where we are:
	Overview and Update of PAGER (Wald; 20 min)
	Summary of Phase I (Semi-Empirical) (Jaiswal; 10 min)
	Phase II (Analytical) Model (Porter; 15 min)
	Phase II (Analytical) Data (Jaiswal; 10 min)
10:10 am	—Break—
10:25 am	Summary of Summer work
	Univ of Thessaloniki (Andreas Kappos—by Skype; 15 min)
	Univ of Bath (Dina D'Ayala; 20 min)
	UCSD (Anna Lang; 15 min)
	IIT Roorkee (Dominik Lang; 15 min)
	IIT Kanpur (Sudhir Jain; 15 min)
11:50 am	Discussion (D'Ayala, All; 40 min)
12:30 pm	—Lunch—
2:00 pm	Univ of Canterbury (Stefano Pampanin—by Skype; 15 min)
2:15 pm	Improved HAZUS Vulnerabilities for PAGER (H. Ryu, N. Luco; 15 min)
2:30 pm	Feedback on summer work, Key Issues (All, 25 min)
	Missing/Estimated Analytical parameters (All; 20 min)
3:15 pm	—Break—
3:30 pm	Calibration (D'Alaya, All; 15 min)
	Next Steps (D'Ayala, All; 15 min)
4:00 pm	Additional countries—(Jaiswal, Wald; 20 min)
	PAGER priority countries
	Where can we use existing data as proxy
	Provide additional contacts (All)
5:00 pm	Close