EEPI Map - Earthquake Engineering Photographic Investigation Map: An Overview

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Abstract

EEPI Map (Earthquake Engineering Photographic Investigation Map) is a tool which enables photographs to be used to investigate building vulnerability to hazards, and analyse post-earthquake event damage patterns and shaking intensity. It is based on a comprehensive geo-referenced photographic database (containing nearly 12,000 photographs) which contains attributes of buildings and engineered structures, and includes a large number of photographs from previous Earthquake Engineering Field Investigation Team (EEFIT) missions. The aim of this work is to increase the utility of photographs in post-event analysis of hazard affected regions. Although the project is independent, it has been designed to be compatible with a number of Global Earthquake Model (GEM) initiatives, including the GEM Earthquake Consequences Database, GEM Inventory Data Capture Tools (IDCT) and GEM's OpenQuake platform (see http://www.globalquakemodel.org).

EEPI Map has the following capabilities:

- EEPI Map can be added to by the public or by professionals, using a mobile application under development, to upload photographs along with building inventory (pre-event) or building damage information (post-event).
- Seismic Experts can inspect uploaded photographs via a web interface and assign geo-locations, building typologies and damage attributes.
- It can be searched online to provide photographs and information on structures useful to engineers, researchers and practitioners.
- Data is stored in an industry-standard geospatial earthquake consequences database structure.
- It can be used as a framework to analyse the attributes of the photographs to give information on building vulnerability, damage level and in the case of earthquakes, predictions of shaking intensity.
- Photographs and associated metadata can be extracted from the EEPI Map server through industry standard interfaces such as WFS and WMS.

1 Introduction

As demonstrated by the photographs currently in the EEPI Map database, photographs are taken as part of the majority of field surveys of earthquake-affected regions. These photographs often form an important part of desk studies conducted after the field survey to analyse damage patterns and shaking intensity. However, previously, the way in which these photographs are catalogued and stored has not maximised the utility of this source of information.

A number of GEM initiatives have provided methods of storing photographs which provide auxiliary information for field survey data. These include the GEM Inventory Data Capture Tools and the International Macroseismic Scale 2014. However, these initiatives use photographs taken by experts in an illustrative way rather than as the central source of inventory or damage information. As photography forms a central part of field surveys conducted by engineers or other experts, utilising these photographs to obtain intensity assignments rapidly seems a logical step.

The EEPI map project was initially focussed on providing a comprehensive geo-referenced online, searchable photographic database useful to engineers, researchers, and practitioners. A large number of photographs, including many from previous Earthquake Engineering Field Investigation Team (EEFIT) missions were stored in the database and the website can also be used as a repository for future field mission photographs. Users assign the EEPI Map photographs attributes, such as damage class, asset class etc. which can be searched to display photographs with the attributes of interest in particular locations. Examples of the search functionality are shown in Figure 1, where a search for Asset Class: Dam and Damage Level 1, displays 4 photographs and Figure 2, where a search for Asset Class: Essential Facility and Damage Level 5, displays 248 photographs from four different events. These basic functions improve current methods of displaying and searching the photographs taken on field missions, e.g. EERI photograph database (available to members of EERI only) and the Virtual Disaster Viewer (http://vdv.mceer.buffalo.edu/vdv/select_event.php).

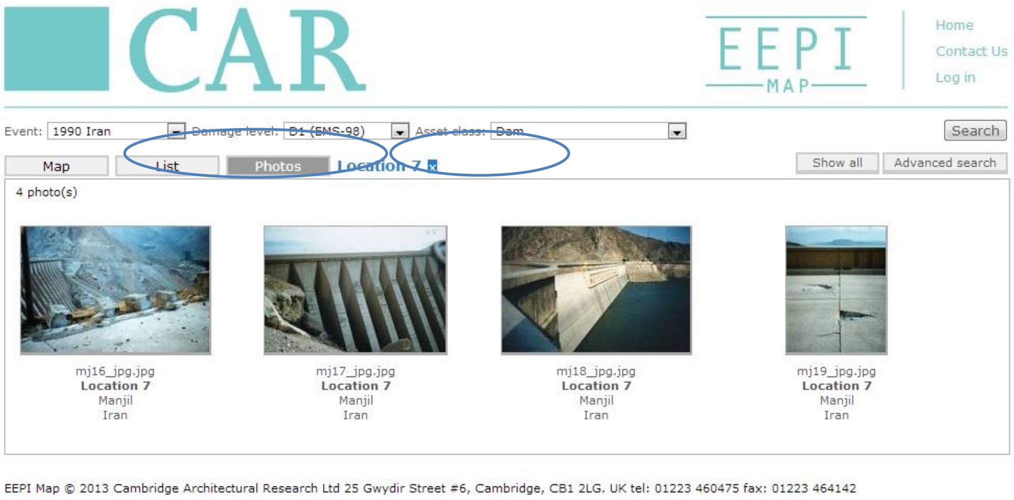

Figure 1: Search results on EEPI map: Asset Class – Dam; Damage Level: 1. Photographs are assigned with attributes which allow users to search the EEPI database.

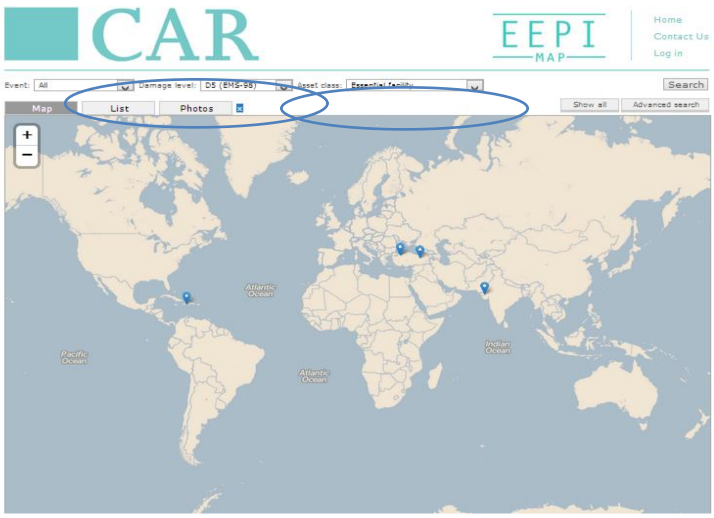

Figure 2: Search results on EEPI map: Asset Class – Essential Facility; Damage Level: 5. Map showing 'Event Locations' of photographs assigned with these attributes.

The initial aim of the EEPI Map project is to provide a tool which standardises the way in which photographs of buildings are taken and stored and allows an analysis of the attributes of the buildings photographed. Although the photographs currently in the EEPI Map database are sourced from field surveys conducted by experts, a future aim of this project is to use members of the public to gather information on earthquake-affected regions post-event. This concept has been explored by a number of projects which have used crowdsourcing post-event to map damage from aerial imagery, e.g. OpenStreetMap Mapmill and Tomnod Disaster Mapper. However, these projects have had mixed success in terms of the number of volunteers who participate and the accuracy of the results, due to the difficulties in getting untrained volunteers to perform a difficult task such as analysing satellite imagery (Foulser-Piggott et al., 2013). However, some projects have a much higher participation rate and still provide technical information, such as the USGS "Did You Feel It?" questionnaires completed by members of the public post-earthquake event. This project aims to take advantage of the large number of people who take photographs of damage and share them through sites such as Flickr, Panoramio and Instagram. However, this future application contains a number of challenges relating to data filtering and validation.

The information provided by EEPI Map is intended to be freely available and will have a number of potential user groups, for example earthquake engineers, insurers, the media and can also be used for education purposes. EEPI Map information on damaged buildings will also form the photographic appendix to the proposed new International Macroseismic Intensity Scale , IMS-14 (Foulser-Piggott and Spence, 2013) , an internationally applicable update to EMS-98.(Grunthal et al.).

The first part of this paper describes the progress of EEPI to date as well as planned system developments. Research on the use of photographs to make building vulnerability, damage and intensity assignments is then discussed, particularly focussed on the definition of standards for the acquisition of photographs of assets post-event. The application of this work to post-event damage assessment and intensity assignments is then discussed and illustrated using photographs collected from three previous earthquake events: the Haiti 2010; L'Aquila, Italy 2009; Bam, Iran, 2001.

2 The EEPI system

EEPI Map separates field survey data collection, in this case taking photographs in the affected area, from the impact assessment operation, which can take place away from the disaster zone.

Photographs are taken in the field by either experts or by members of the public (crowdsourcing) and photographers are encouraged to use the guidelines presented in Section 3 to facilitate analysis of building characteristics and damage. The photographs are uploaded to EEPI map. Assessors can then access the photographs building by building basis remotely over the web and assign impact measures. Building damage can be assessed far more readily when the photographs are organised by building rather than being in an unstructured list.

Underpinning EEPI Map is a database that has been designed in a way that helps remote assessors to extract quantitative information from field survey photographs. It is organised around the locations of assets being photographed because it is with the assets – rather than the photographs – where the important information resides. EEPI Map provides a comprehensive asset database structure, based on industry standards and expertise that has been gained from CAR's extensive experience in post disaster surveys and data gathering.

2.1 Technical System Requirements

The key technical requirement for EEPI Map is to derive quantitative earthquake engineering data from photographs. This distinguishes EEPI Map from traditional qualitative photographic database and sharing websites. Furthermore, EEPI Map employs human expertise to add quantitative value to photographs remotely from the data gathering itself. Thus EEPI Map offers a new paradigm to the traditional post disaster field survey – photographs are gathered in the field potentially by crowdsourcing, using standardised protocols for photographing buildings (see section 3), and data is derived from the photographs away from the disaster zone by an expert using a remote web based interface into the EEPI Map system. This provides a framework that can be used to guide data gathering in the field and for subsequent research investigation.

Typical workflow for EEPI Map is as follows:

Take photographs: Post disaster photographs are taken in the field by a variety of professional and public photographers. EEPI Map publishes photographic gathering guidelines. Photographs need to be taken with a camera that applies date stamp, GPS location and ideally direction.

Upload: Upload photographs to the EEPI Map website. A mobile application under development, can aid with this by storing photographs until a network connection is available and then automating upload.

Store: Data is stored in a geospatial database structure.

Expert inspects and curates online: Seismic Experts inspect uploaded photographs via a web interface and assign to structures, building typologies and damage attributes and comments

Search online: EEPI Map can be searched on line to provide photographs and information on structures useful to engineers, researchers and practitioners.

Framework for apps: EEPI Map can be used as a framework to analyse the attributes of the photographs to give information on building typology, inferred vulnerability, damage level and in the case of earthquakes, predictions of shaking intensity.

Remoting: Engineering data, photographs, thumbnails and photographic meta-data can be extracted from the EEPI Map server through industry-standard interfaces such as WFS and WMS.

This workflow helped to define the system design and user interface of EEPI Map. Further requirements include the use of Open Source components, using the Cloud and the adoption wherever possible of industry standards used within the earthquake consequences scientific community.

2.2 Technical approach

EEPI Map needed an industry standard modelling environment and database capable of storing catastrophe consequence data and providing engineering analysis. For this we chose the technical architecture and data format of OpenQuake, by the Global Earthquake Model (GEM) (globalquakemodel.org). Their Earthquake Consequences Database (Ruffle and Smith, 2013) provides a well-developed database format for the storing of post disaster earthquake damage and casualty data for a variety of built structure types and for both primary shaking and secondary hazards such as tsunami, and uses GEM's peer-reviewed Building Taxonomy 2.0.

Previously GEMECD had a simple photographic storage model and we were able to work closely with the GEM software developers to enhance their database schema to support our requirements. Consequently GEM has benefitted from EEPI Map by getting more advanced photographic storage capabilities in their own Consequences Database.

By deciding on compatibility with OpenQuake this guided us to a choice of base technologies as follows:

- *PostGIS* for relational database with Open Geospatial Consortium (OGC) geospatial extensions (http://postgis.net)
- *Python* for programming language (http://www.python.org)
- *Django* for web and database framework (https://www.djangoproject.com)
- *Geoserver* for server side mapping engine (http://geoserver.org)
- *Leaflet* for JavaScript mapping API (http://leafletjs.com)

EEPI Map needs to be able to handle photographs, typical requirements being the ability to handle bulk upload, read meta-data out of photograph files and to produce thumbnail images on the fly for web display. For this we chose an open source image management plug-in for Django called *Photologue* (https://github.com/jdriscoll/django-photologue).

2.3 Internal Design

EEPI Map follows the basic structure of GEMECD in that it holds a historic catalogue of earthquakes called *events*. Within each event are a number of *studies* which form wrappers around particular data sets. For example a particular photographer in the field would have their photographs assigned to an individual study. Studies then contain attributes including: a damage scale, casualty scale, building inventory class and other classification data that can be customised to the requirements of a particular data provider. These are described in more detail in Section 3.3.

Studies contain *locations*. A Location is a flexibly defined concept that can be any kind of physical place. It could be as general as a city or a town; it could be a marketplace or a street; it could be an administrative region such as a county; or it could be as specific as an individual building in a compound. Locations are stored in the OGC "Well Known Text" (WKT) mark-up language which is capable of storing a variety of geospatial object types from a simple point to a multi-polygon.

Photographs are attached to locations. Thus we come to a key design decision of EEPI Map, to store photographs with a location. This reflects our view that photographs do not just exist in their own right, they are taken *of something*. Hence the expert inspection phase of the workflow consists of transferring the knowledge gained by looking at photographs of a given location, and assigning attributes to that location (not to the photograph per se). Thus, ultimately, searching and analysis of the data in EEPI Map focusses on locational data.

A simplified database design block diagram is shown at Figure 3.

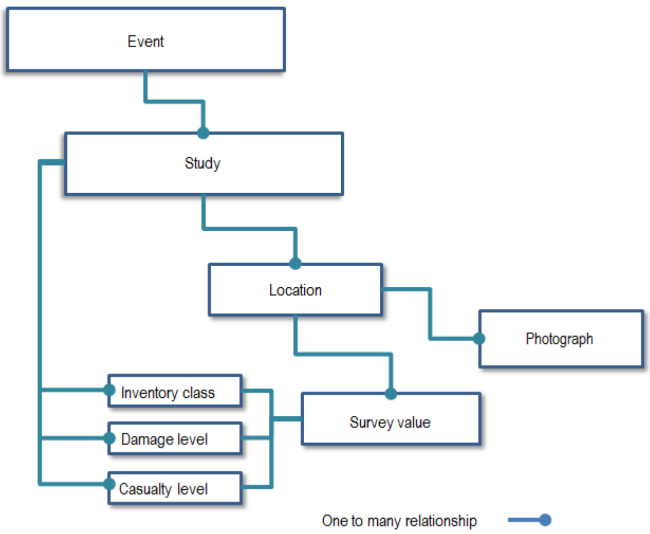

Figure 3: EEPI Map simplified database block diagram

2.4 Implementation

EEPI Map has been implemented on a cloud server running Linux Ubuntu 12.04. Web pages are developed in HTML 5 and thus EEPI Map will run only on recent browsers. The client side mapping is done by Leaflet which receives its maps from the mapping server in the GeoJSON format. Clicks on maps are handled by AJAX requests back to the web server.

The interfaces are, (* denotes publically accessible)

- Public website for browse and search http://eepimap.com*
- Mapping server Web Feature Service (WFS) and Web Map Service (WMS) URI interface*
- Mapping server REST interface*
- Photograph thumbnail cache*
- Uploading interface
- Experts' remote investigation and classification tool
- Engineering analysis tools
- Administrative web interface http://eepimap.com/admin
- Mapping server web interface http://eepimap.com:8080/geoserver/web/
- Database management console

EEPI Map's development is done under Windows using the PyCharm IDE/debugger, dbSchema database design tool and pgAdmin database management program. Code is stored in the GitHub repository.

2.5 User Interface Design

The home page of EEPI Map is a world map showing markers for all the earthquake events in the database (Figure 4). Mousing over the markers gives the name of the event and the number of photographs available for that event. Clicking on the marker gives an option to view locations on a map or view all the photographs for that event as a thumbnail gallery. If locations are viewed on a map, the map zooms to the extent of locations for a single event and markers are shown for each location. Clicking on a location shows a popup with a sample thumbnail photograph and basic engineering data if available (Figure 5) and options to view the photographs for that event as a thumbnail gallery or to go to the full information page for that location. Clicking on a photograph thumbnail takes the user to a photograph detail page with a large screen display with meta-data about the photograph alongside.

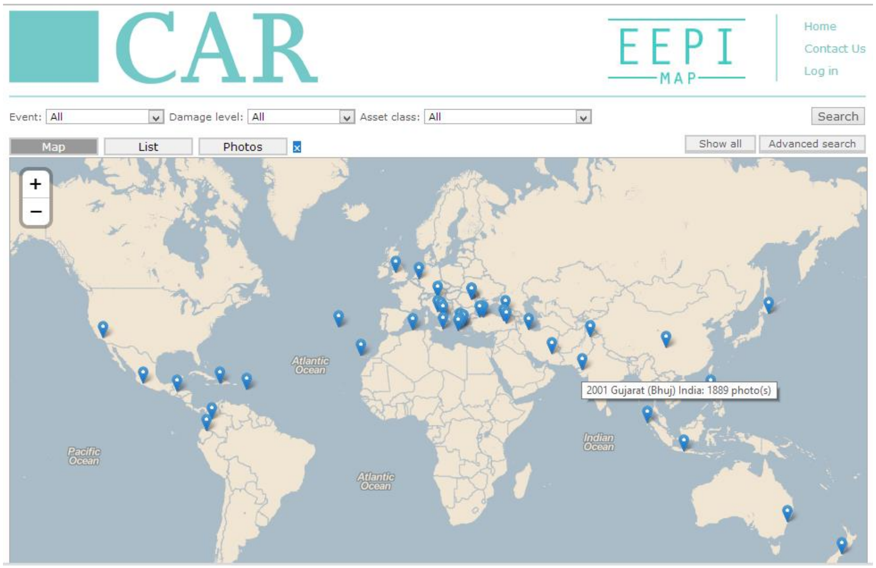

Figure 4: EEPI Map Homepage. Displays locations of events. Hovering the mouse over an event indicates the number of photographs assigned to it.

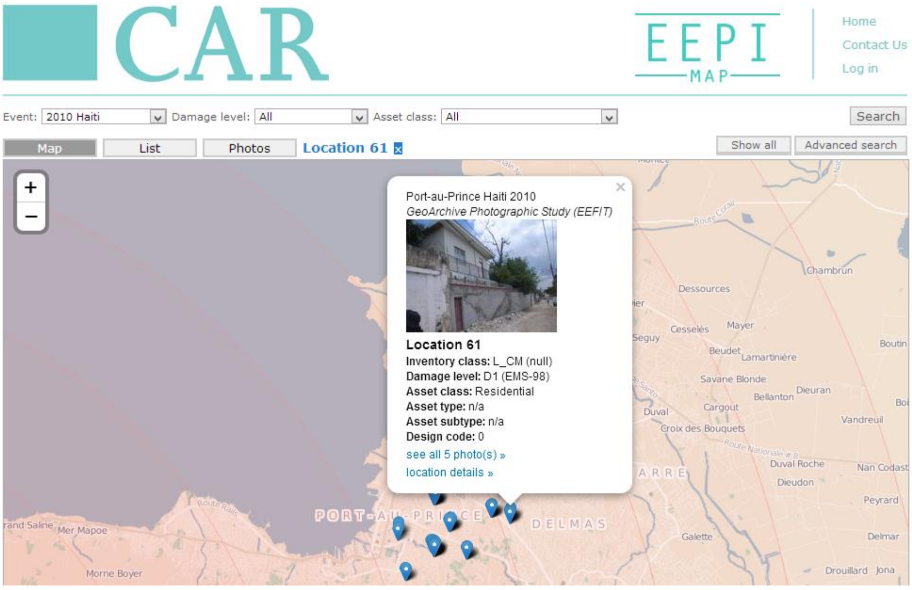

Figure 5: Map displaying photographs and their locations in Haiti. Clicking on a location displays a thumbnail photograph and its attributes (discussed in section 3.3)

2.6 Planned future activities

The EEPI Map project has a number of immediate aims for development, which include the acquisition of more photographs and modifications to the existing cataloguing system and database. There are also a large number of planned extensions, enhancements and applications of the EEPI Map which would ultimately provide an extremely useful tool for the analysis of pre and post-disaster images for earthquake risk assessment. These include the following:

Short-term development ideas (before or shortly after the report is published):

1. Redesign of eepimap.com web interface and navigation structure
2. The search, upload and expert assessment systems are still under-development
3. Structure types defined in a simple way (as well as/instead of GEM Taxonomy) – i.e. EMS-98 or IMS-14. Structure types defined so that vulnerability can be easily inferred.
4. Search for damage greater than a certain level.

5. Assign typical vulnerabilities based on EMS/IMS-14 – automatically given structure type in a particular region.
6. Display things on the map by colour – e.g. colour the markers by damage level; colour different structure types/ vulnerabilities
7. Store and use GDAM boundaries or other boundaries for cities, to allow intensity assignments to be made in a defined area such as a department; region etc…
8. Allow users to select a study area for which they wish to calculate intensity.
9. Automatically create vulnerability/damage matrix for the study area.

Long-term development ideas:

1. Development and implementation of a many to many data model to allow photographs to be linked to more than one location.
2. Development of a smart upload facility for photographs which would include:
   - Automatic extraction of photograph attributes from photograph file EXIF data.
   - Design and development of a bulk picture sorter.
   - Development of methods to facilitate assignment of key engineering characteristics (building type, damage level, etc.) to photographs.
3. Using data-mining of open-source products, e.g. OpenStreetmap, to enable automatic association of geo-referenced photographs to a location and extraction of location data, e.g. building class.
4. A future development would be improving the estimation of intensity from crowd-sourced photographs by exploring clustering methods for the data and interpolation techniques.
5. Extension of the EEPI Map to provide crowdsourcing functions, enabling users to upload their own photographs taken post-disaster. Development of the EEPI App to allow this to be done in the field.. This would also include methods of user login management, filtering and validation of photographs.

3 Photograph Standards

3.1 Field investigations

Following a high intensity earthquake, a field investigation is often made. Team members typically include people with an engineering background, both geotechnical and structural, as well as seismologists (Musson, 2009). EEFIT (1993) give the following guidance regarding data collection in a field mission which is relevant to the standards that should be produced to maximise the utility of photographs.

In the field, it is necessary to combine both detailed and general surveys of structural behaviour. Structures need to be surveyed in terms of:

- The distribution of different types
- The overall vulnerability of typical structures
- Deviations in terms of good or bad examples of typical structures
- Distribution of different grades of damage within each building type.

Care should be taken over making accurate records of the location of all structures studied or photographed and data should be gathered as written notes and photographs.

For engineered structures, damage should be recorded in order to:

- Identify both good and bad performance in a sample of both damaged and undamaged structures.

- External and internal damage
- Typical modes of failure.

In order to assign damage levels so intensity assignments can be made, the following are required:

- Information on the strength of the building is required
- Strengths and weaknesses in the construction techniques
- Special points of poor vulnerability or high resistance
- Irregularity or symmetry in the building design
- The quality of the materials used.
- Information on local earthquake-resistant design regulations and code enforcement
- Extent and types of damage to non-engineered structures

EEFIT (1993) gives the following specific guidance regarding photographic studies:

- Detailed photographic surveys can be made of individual streets or districts to record the percentages of various types of buildings that were damaged to a lesser or greater degree.
- These surveys should be supplemented with internal records from at least a sample of the buildings examined.

The EEFIT reports demonstrates how photographs form an essential part of a field study. Therefore, the guidelines provided in EEPI Map aim to maximise the utility of photographs and allow analysis of building vulnerability and damage patterns to be undertaken. There are two ways in which photographs may be gathered to be added to EEPI Map, namely crowdsourcing and field survey by experts. Requirements for these photographs and general guidelines for collection of this data both by experts and the public are now described.

3.2 Requirements for photographs to be used in vulnerability and damage assessment

During the initial stages of formulating the EEPI map database, a number of problems which created difficulties identifying the building and its' characteristics were noted. These included:

- Photographs of only one elevation of a building
- Lack of detailed photographs regarding a building's material type
- Photographs had no GPS metadata or locational reference

In order to use photographs to assess the intensity, vulnerability and damage levels in an area following an event, these problems need to be overcome and the collection of photographic information needs to be standardised using the following guidelines:

3.2.1 Elevations

In a given location, photographs should be provided of more than one elevation i.e. the front elevation and a side elevation. This will help the remote analyst to identify the structural system, damage level and asset class. The importance of having photographs of different elevations can be seen in Figure 6. The damage level of the building appears to be lower when viewing the front elevation in comparison to viewing the side elevation. In order to assign an accurate damage level, the remote analyst needs an indication of the entire structural system, not just part of it. Hence, photographs of a range of elevations help to eliminate these errors.

Figure 6: Front (left) and side (right) elevation of a reinforced concrete frame building, Bam, Iran, 2003. Source: EERI. It is vital to have pictures of a range of elevations to understand the entire structural system and assign accurate damage levels i.e. if only one photograph was supplied, the front elevation would be assigned damage level D3, whereas the side elevation would be assigned D4.

3.2.2 Photographs of Details

As recommended by EEFIT (1993) additional photographs should be provided of irregularity in the building design and special points of vulnerability. Detailed (zoomed in) photographs of a building's structure allow for a more accurate analysis of material type and the type/level of damage, as shown in Figure 7

Figure 7: Overall structure (left) and detailed photograph (right) of a reinforced concrete frame building with brick infill walls, Bam, Iran, 2003. Source: ERRI. A 'detailed photograph' (right) provides a remote analyst with additional detail regarding the material type and damage to the building.

3.2.3 Locating the Photograph

As previously mentioned, problems locating a photograph can occur if there is a lack of GPS metadata. If a GPS camera is not available, the field investigators should assign a number to buildings and identify this on a map (see Figure 8). This will allow the remote analyst to accurately locate the buildings.

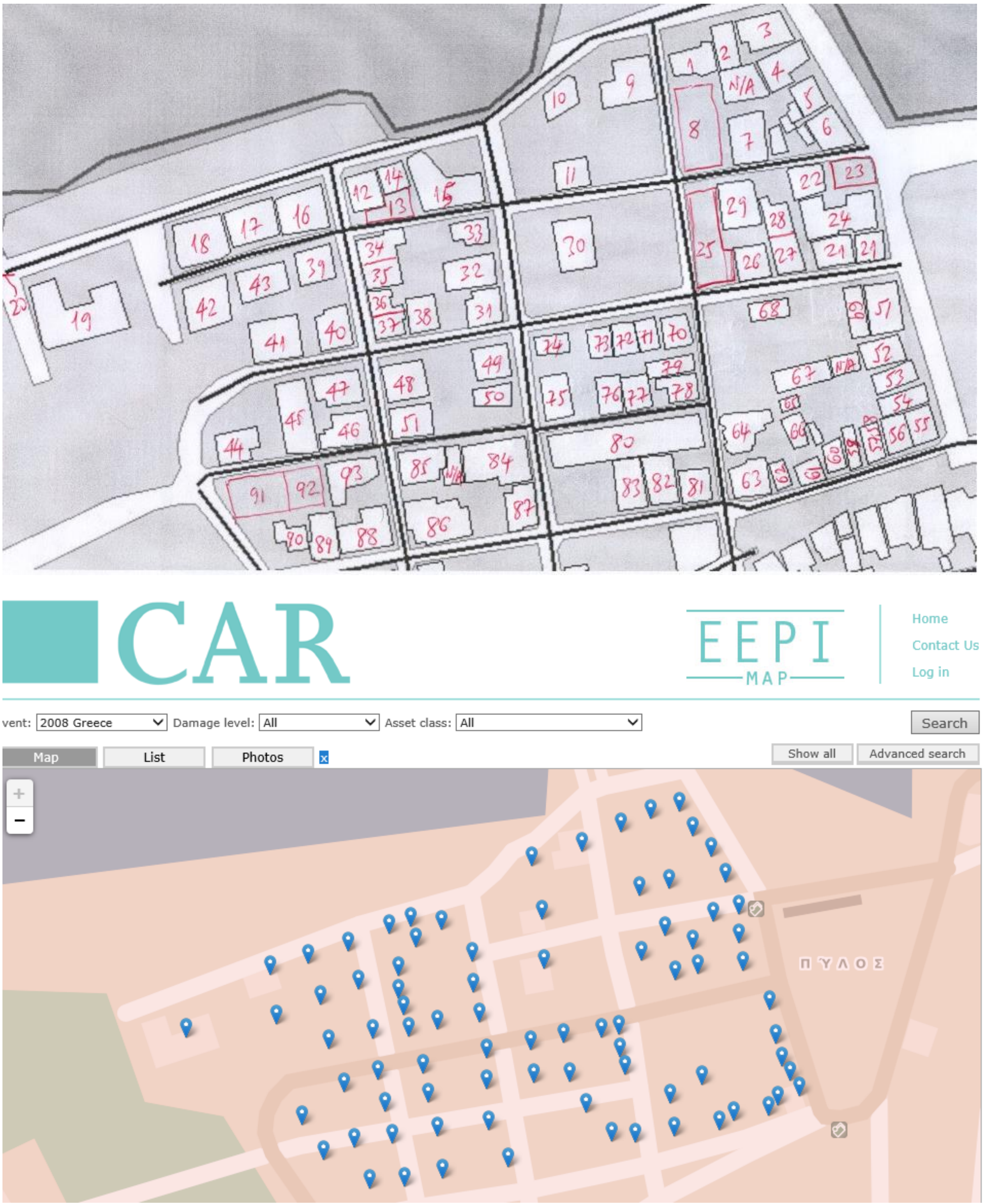

Figure 8: Pylos Vulnerability Street Survey Map (Top); 'EEPI Map' photograph location map (bottom). Pylos Survey, June 2008. During the field survey, buildings were assigned a number which was identified on a map (top). This allowed the remote analyst to accurately locate the buildings on EEPI map (bottom) and assign the photographs to the correct location.

3.3 Damage patterns and intensity assignments overview

Assigning attributes (discussed in section 2.3) to a photograph allows different users of EEPI Map to use it in different ways depending on their needs, i.e. search functions which could be beneficial for educational/research purposes and the assignment of damage and intensity patterns, discussed in sections 3.3.1 – 3.3.3. The following table describes some of these attributes in more detail:

Table 1: EEPI Map – Photograph's Attribute Assignment: Photographs within EEPI map can be assigned different attributes, which can be beneficial for different users i.e. search functions or assigning vulnerability classes.

	Attribute	Description	Example (s)	Use
Main Attributes	Event	Link to Global Earthquake Model (GEM) Earthquake Consequences Databases	2010 Port-au-Prince, Haiti	Identifies magnitude of earthquake, epicentre and other characteristics.
	Damage Level	Classification (D0-D5) of damage to buildings.	See section 3.3.3	Damage patterns and intensity assignments - See section 3.3.3
	Type of Damage Code	Code describing the type of damage	Soft Storey Collapse; Pancake Collapse; Shear Failure etc…	Search functions and additional detail i.e. if the user needs a photograph of a specific type of collapse.
	Asset Class Asset Type Asset Sub-Type	Codes describing the use/type of the building/infrastructure.	Hospital; Dam; School; University etc…	Search functions i.e. if the user needs photographs of a particular type of building.
	Structure Type	Code describing the structure of the building in the photograph	See section 3.3.1	Search functions; and damage patterns and intensity assignments. See section 3.3.1
Detailed Attributes	Days after the Event	Number of days after the event (in some cases before).	10 days	Comparisons and monitoring of reconstruction.
	Time of Day	Indication of when the photograph was taken.	AM or PM	Allows for comparisons before and after, aftershocks.
	Subject Orientation	GPS subject orientation of the photograph i.e. direction of photograph.	200^{o}	Distinguishes between different elevations (see section 3.2.1)
	Photographer Profession	Indication of the profession on the photographer i.e. was the photograph taken as part of a field investigation or uploaded through crowdsourcing.	Member if the public (crowdsourcing); field research etc…	Additional detail and filtering purposes i.e. only view photographs from a field survey.
	Photograph Quality Code	Code indicating the quality of the photograph.	1* = Very Good 1 = Good 2= Average 3 = Poor	Search and filtering purposes.
	Subject Code	Code describing the subject of the photograph.	Road; landslide; general building; infrastructure etc…	Has similarities with asset class but can provide additional detail and is useful if the exact location cannot be assigned.
	City Scale Code	Indication of the photographic context and surroundings.	Aerial photograph; Individual	Search and filtering purposes i.e. having a view of an entire street

			Building; Street Scene; City View	can be useful for assigning intensity levels.
	Type of Structure in Photograph	If applicable, a code describing the structure shown within the photograph.	Column; beam; roof; wall; foundations; reinforcement; floor	Allows EEPI Map users to search for photographs of certain structure elements i.e. Columns or Beams
	Addition Photograph Characteristics	'Tick Boxes' indicating whether the photograph is: -Of a detail -Has an indication of scale -Is internal -Has the owner/other people within the photograph	Yes/No	Search and filtering purposes.

3.3.1 Structure Type

When assigning damage and intensity patterns, the photographer or analyst begins by assigning a structure type to the building photographed using the descriptions of structure types included in IMS-14. As discussed in section 3.2.2, detailed photographs will help aid this assignment (Table 2).

Table 2: Structure Type Definitions. Source: International Macroseismic Scale.

Type	Sub-type	Description	Principal variants included	Photographic Example
M1	Weak	Load-bearing walls of weak masonry, either earthen (adobe or rammed earth), or rubble stone in lime or mud mortar; roof of timber poles or joists, covered with earth or metal sheet; generally single storey.	Thick rubble stone masonry walls in older buildings in rural Europe, Turkey; adobe block construction in South America; *bahareque* buildings of rural South America with mud and timber lacing; rammed earth walling in some parts of rural Europe, South America.	 *World Housing Encyclopaedia (2013a)*
M2	Unreinforced	Load-bearing walls of unit masonry, brick, concrete block or stone, laid in courses with mortar of cement or lime; floors either of reinforced concrete or timber joists supporting timber boards; roofs generally pitched and covered with tiles or metal roof sheet, occasionally reinforced concrete; generally up to 3 storeys, sometimes up to 6 stories.	Typical European residential building construction from 18th century onwards, many historical structures; individual buildings and long terraces; older commercial and industrial structures; retrofitted structures using steel ties (USA); cavity wall construction (parts of Europe, since 1930's).	 *D'Ayala, D.*

M3	Structural	Load-bearing walls of reinforced or confined masonry; floors either of reinforced concrete or timber joists supporting timber boards; roofs generally pitched and covered with tiles or metal roof sheet, occasionally reinforced concrete; generally up to 3 stories.	Reinforced masonry (Europe, USA) with vertical and horizontal reinforcing bars within the masonry; confined masonry (Mexico, South America) with small reinforced concrete members framing and confining masonry load-bearing walls.	 *Tena-Colunga, A. et al (2010)*
RC1	Frame	Loads carried by reinforced concrete moment-resisting frame consisting of beams and columns; infill walls of masonry or other materials; floors and roof generally of reinforced concrete, sometimes precast; single up to multi-storey.	Frames with a variety of infills, frames with in-situ walls for lifts and stairs only; flat slab construction; precast frames; ductile or non-ductile detailing; pre-code, early code, modern code; low-rise, mid-rise and high-rise	 *Marhatta, Y.B. et al (2007)*

RC2	Shear wall	Loads carried by reinforced concrete bearing-wall, or by an infilled reinforced concrete frame with additional regularly-spaced reinforced concrete walls, floors and roofs generally of reinforced concrete, sometimes precast; single up to multi-storey.	Perimeter concrete bearing-wall system, using in-situ concrete; in-situ concrete frame with regularly-spaced shear walls in each direction to carry lateral loads; precast concrete panel wall system (esp. former USSR)	 *Moroni, O. et al (2002)*
S	Steel Frame	Loads carried by steel frame, either moment-resisting or braced, with infill walls of a variety of materials, floors and roofs of timber joists and panels, reinforced concrete or metal deck on steel beams, single up to multi-storey.	Moment-resisting frame; concentrically braced or eccentrically braced frame; steel frame infilled with masonry or reinforced concrete or lightweight panels; steel frame encased in reinforced concrete; pre-code, early code, modern code; low-rise, mid-rise and high-rise; lightweight steel frame, low-rise.	 *Alimoradi, A. (2002)*

T	Timber Frame	Loads carried by a timber frame, either with closely spaced stud walls with timber cladding or brick veneer; or more widely spaced post and beam construction with masonry or other infill,; floors and roofs of timber joist construction, roofs normally pitched with covering of tiles or metal sheets; generally single up to 3 stories.	Timber stud-wall construction; post and beam construction; heavy timber construction with infill masonry (*himis* Turkey, *Dhajji Dewari*, India), traditional Japanese timber frame construction.	 *Timber Building, World Housing Encyclopaedia (2013b)*

3.3.2 Vulnerability

The structure type is then used to define the expected vulnerability: Class A - F (Foulser-Piggott and Spence 2013), as shown in Table 3.

Table 3: Vulnerability Table – Vulnerability is dependent on the type of structure assigned to the building/photograph. Expected vulnerability is indicated by a circle and the range by vertical lines (R. Foulser-Piggott, R. Spence. 2013).

Type of structure		Vulnerability Class					
		A	B	C	D	E	F
Masonry (M)	Weak	O	I				
	URM	I	O	I			
	Structural		I	O	I		
Reinforced Concrete (RC)	Frame		I	O		I	
	Shear wall			I	O	I	
Steel (S)	Frame		I	O		I	
Timber (T)	Frame		I		O	I	

In order to obtain the appropriate vulnerability, it is necessary for the analyst to consider elements of the building which may modify the expected vulnerability, moving it towards the upper or lower bound.

As the photograph is geo-located, the location is automatically added as a modifier of the expected vulnerability for the building, e.g. Masonry buildings in Iran (Zone 3) would have a higher vulnerability than masonry buildings in Italy (Zone 1). The location of the building would also consider whether or not the country has any building codes and the expected level of code compliance.

The photographer or analyst may record other modifier values by analysing the photograph and building characteristics and modifying the vulnerability accordingly. This may include the quality of construction. Figure 9 shows an example of low quality confined masonry compared to that shown in Table 2, class M3. This will modify the vulnerability class from C to B. Figure 9 also shows an example of an increase in vulnerability due to vertical irregularity. Although a reinforced concrete frame buildings' expected vulnerability may be class C, similar to poor quality construction, the soft storey increases the vulnerability to B. An example of a modifier which decrease a building's vulnerability are earthquake-resistant design features, which would decrease a building's vulnerability.

Figure 9: Vulnerability Modifiers: Poor quality confined masonry construction, Haiti, EEFIT, 2011 (left); irregularities in plan i.e. soft storey, L'Aquila, 2009, EEFIT (right). Poor quality construction and irregularities in the plan, both increase a building's vulnerability thus a higher vulnerability class will be assigned by identifying these features from the photograph.

3.3.3 Damage Level

The estimation of building damage level from a photograph is performed in much the same way as in a field survey. The photographer or analyst assigns an IMS-14 (EMS-98 updated) damage level based on the guidance notes and pictorial representations of damage in the scale document. The analyst can also make use of the photographs in EEPI map of similar building types and damage patterns. As discussed in sections 3.2.1 and 3.2.2, having a front and side elevation and detailed photographs of the building will lead to more accurate damage level assignments. The photographs in Figure 10 show some examples of how a building damage level can be identified from a photograph.

Figure 10: Example of classification of damage to mixed structural classifications of buildings.

4 EEPI Map post-earthquake applications

As discussed in the previous section, photographs taken post-event by either experts or members of the public can give extremely useful information concerning the extent and type of damage in a region. Using the guidelines on the website described, each location photographed can be assigned a vulnerability class and damage level. The following sections explore how the collected photographic data stored in EEPI map can be used to provide building characteristics and estimate shaking intensities.

The first step is to decide how the information for each location should be spatially grouped in order to construct an intensity map. This is highly dependent on the following factors:

- The number of and the spatial distribution of buildings photographed in close proximity.
- The photographer's aim: i.e. is the cluster of buildings part of a survey or an attempt to assign intensity in a location
- The predicted homogeneity of earthquake ground motion, e.g. are soil conditions and topography homogeneous etc.
- The distribution of building typologies in the sample and whether the range of vulnerabilities encountered allows a reasonable estimate of intensity in that region.

There are numerous possibilities for determining the clustering of buildings for intensity estimation and the surveyor or analyst should decide on the grouping of the buildings for intensity assignment, based on the guidelines provided in the EMS-98 document (Grünthal, 1998). This document suggests that data should be grouped by place prior to assessing intensity. By "place" is meant a village or town or part of a city. Places should not be too big (like a county) or too small (like a single house). When assessing intensity for a place, all the data relating to that place should be considered together. If there are fifteen reports from one village, a single intensity should be assigned to those fifteen jointly, rather than making fifteen assessments and combining them.

EEPI Map will provide two options:

- The user can choose to create a study, for which the intensity will be estimated based on all buildings in that study area.
- For crowdsourced photographs, estimates of intensity will be provided for each region defined according to appropriate sub-national boundaries.

For the defined region, EEPI Map then automatically gives a damage-vulnerability matrix, which can be used to estimate a range of possible intensities for the study area or other defined area.

Musson (2009) notes that although the conversion of descriptive information to numerical intensity data by use of an intensity scale is fundamental to macroseismic studies, the process has in general been rather poorly documented. Musson also discusses the problems inherent in intensity assignments with insufficient or inadequate data and the importance of assigning ranges of intensity rather than "forcing" a value of intensity on a study area based on inadequate data.

Musson also gives useful guidance on the assignment and display of intensity. The use of automatic algorithms to assess intensity by computer has been explored at least since the 1980s. The advantage of automatic procedures is that any possible subjectivity or bias can be removed from the procedure, however, algorithms require calibration and review of estimates. Wald et al. (1999) demonstrate that the combination of algorithms for intensity assessment with on line questionnaires allows intensity maps to be produced rapidly post-event. The intensity data collected is then displayed as a map or ShakeMap, using contour lines of equal intensity, called isoseismals. An isoseismal can be defined as a line bounding the area within which the intensity is predominantly equal to, or greater than, a given value.

4.1 Damage patterns and intensity assignments example

In this section, an example methodology is presented which obtains intensity assessments from photographic damage information from the 2010 Haiti Earthquake. This methodology uses the principles outlined in Section 3.

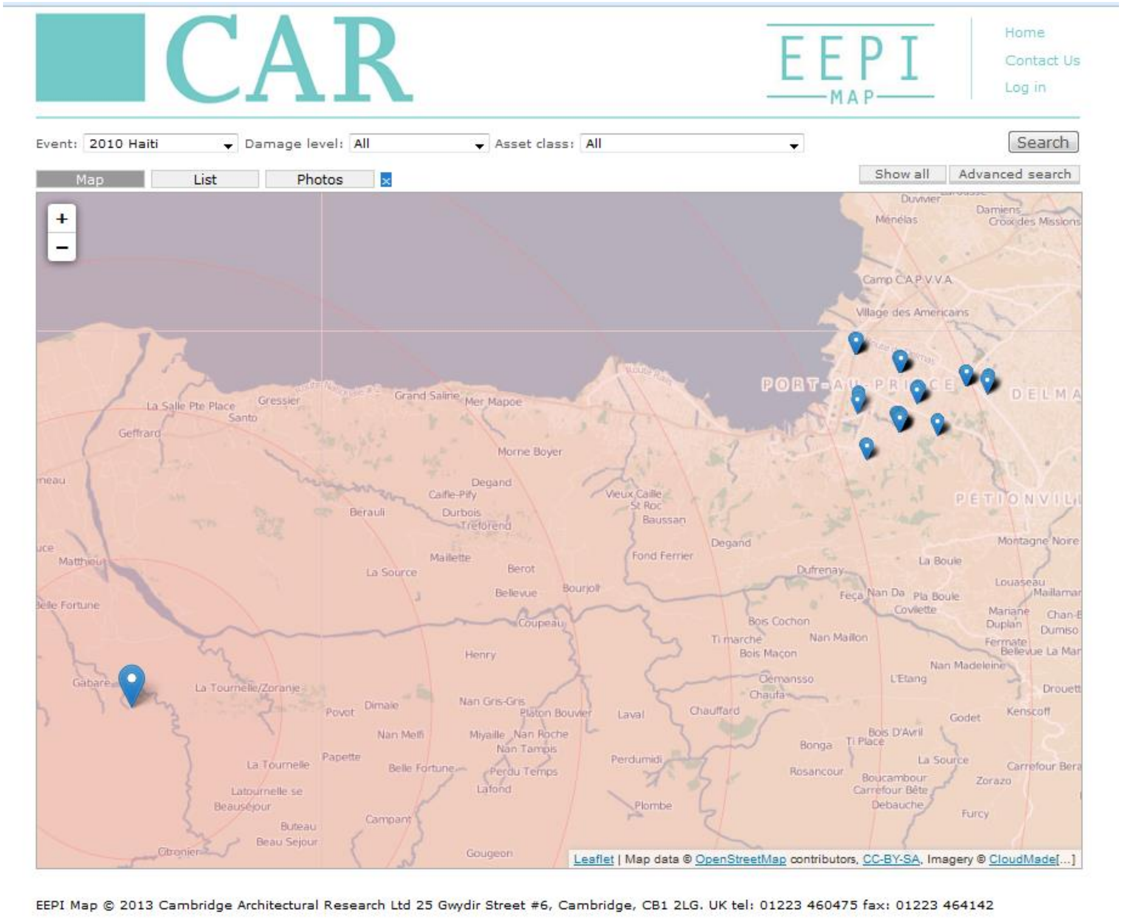

Figure10: EEPI Map event information and photograph locations for Haiti Earthquake 2010

The first step was to use the building typology information stored in EEPI map to assign a range of possible vulnerabilities for each building type. The expected vulnerability was increased for the majority of building types due to a low level of earthquake resistant construction in Haiti. The expected vulnerability of each building type class identified in EEPI Map is shown in Table 4.

Table 4: Structure types and vulnerabilities from Haiti 2010 event photographs.

Structure type class	Structure type description	Expected vulnerability	Lower bound vulnerability	Upper bound vulnerability
L_CM	Low rise confined masonry	B	B	D
S_CM	Single storey confined masonry	B	B	D
S	Single storey informal construction	A	A	E

L_RCF-I	Reinforced concrete frame with infill	B	B	E
L_RCF	Low rise concrete frame with infill	B	B	E
S_RCF-I	Concrete frame with infill	B	B	E
CM	Confined masonry	B	B	D
L_TF	Low rise timber frame	C	B	E
S_M	Single storey mixed materials	A	A	A
L_RCF-0.5I	RC frame with half height infill	B	B	E
S_RCF	Reinforced Concrete Frame	C	B	E

Assigning the above expected vulnerabilities to the structure types shown in each photograph and using the damage levels assigned by the field survey team (EEFIT, Booth et al.), the damage and vulnerability matrix for the photographed locations in Haiti can be developed, shown in Tables 5a and 5b. These tables give the percentage of buildings in the study area with a particular vulnerability class and damage level.

Table 5:Damage (column headings as per EMS-98) and vulnerability (row headings as per EMS-98) matrix for Haiti event 2010.

(a) - damage and vulnerability matrix - abs						
	1	**2**	**3**	**4**	**5**	**sum**
A	6	0	2	1	0	9
B	19	15	17	10	18	79
C	2	2	0	0	1	5
D						
E						
						93

(b) - damage and vulnerability matrix - %						
	1	**2**	**3**	**4**	**5**	sum
A	6%	0%	2%	1%	0%	10%
B	20%	16%	18%	11%	19%	85%
C	2%	2%	0%	0%	1%	5%
D						
E						
						100%

In order to apply the mapping from damage and vulnerability assignments to intensity, the tables are simplified to give a qualitative damage and vulnerability matrix (based on the EMS-98 fuzzy mapping procedure), where:

- Few = 0 – 20%
- Many = 20-60%
- Most = 60 – 90%
- All = 100%

The proportion of buildings in the study area with each vulnerability-damage combination is then used along with the definitions of the intensity levels found in the EMS-98 scale to provide an estimate of intensity using a simple algorithm of “if statements”. For the Haiti earthquake, based on the photographs in EEPI Map, the expected intensity is X, which corresponds to the maximum observed intensity in the study area from ShakeMap (http://earthquake.usgs.gov/earthquakes/shakemap/global/shake/2010rja6/).

This section has demonstrated how photographs can be used to provide an intensity estimation for a study area. It should be emphasised that this exercise is illustrative of what may be achieved using photographs for intensity assignment and damage patterns, but does not allow the limitations of the approach, such as sample size, biased sampling or photographing of damaged buildings and other issues with qualitative measures of earthquake shaking intensity to be fully explored.

5 Conclusions

The overall aim of the project is to provide a free tool for the investigation of Earthquake-induced damage based on photographic records. EEPI Map also provides a valuable database of structure type and vulnerability information worldwide.

Although housing some 12000 photographs, the EEPI Map project is at an early stage of development. Over the next few months, considerable enhancements to the website and the crowdsourcing functionality are planned as outlined in this document.

If you are interested in contributing to EEPI Map, or would like further information, please contact: Dr Roxane Foulser-Piggott, roxane@carltd.com.

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