

The GEM earthquake consequences database and New Zealand's contributions

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ABSTRACT: The Global Earthquake Model Earthquake Consequences Database (GEMECD) is one of the risk component projects of the Global Earthquake Model (GEM). GEMECD is led by a consortium including: Cambridge Architectural Research Ltd. In UK (leading institution) and partners from Latin America, Asia, North America, Middle East and Oceania. The aim is to make possible, for the first time, the easy and open access to data on the physical, social and economic impacts induced by earthquakes all over the world. The GEMECD database includes 71 worldwide events from 1970 onwards and will be accessible via OpenQuake. GEMECD provides a standardised framework for collecting and collating geocoded consequence data induced by primary and secondary seismic hazards to different types of buildings, critical facilities, infrastructures and the population. This paper summarises, firstly, the GEMECD structure and main activities, the proposed methods to collect and standardised the data and the proposed outputs. Secondly, New Zealand's contribution to the GEMECD database is described, including the data collection and analysis of 4 earthquake events localised in the South Pacific area, (namely Newcastle, 1989; Luzon 1990; South of Java 2006; and Samoa Islands 2009) and 3 NZ-specific events, namely Edgecumbe (1987), Darfield (2010) and Christchurch (2011). Particular focus will be given to the Darfield and Christchurch events, for which the damage and impacts on the built-environment has been surveyed and collated in different databases "owned" by different agencies and research institutions. The NZ contribution to GEMECD, represented an opportunity for collating, comparing and reviewing existing databases and for uniformising them into a common, openly accessible and standardised database.

1 INTRODUCTION

The Global Earthquake Model Earthquake Consequences Database (GEMECD) is one of the risk component projects of the Global Earthquake Model (GEM). GEM is a legal entity in the form of a non-profit foundation based in Pavia, Italy. Since 2009, GEM is constructing for the first time a global earthquake model to provide organisations and people with tools and resources for transparent assessment of earthquake risk anywhere in the world. By pooling data, knowledge and people, GEM acts as an international forum for collaboration and exchange, leveraging the knowledge of leading experts for the benefit of society (URL: <http://www.globalquakemodel.org/>). The aim of the GEMECD project under the auspices of GEM, is to make possible, for the first time, the easy and open access to data on earthquake consequences, collected as part of reconnaissance surveys, carried out after important recent or historical earthquake disasters around the globe.

Reconnaissance surveys aim to record the direct impact of earthquake ground motion as well as those due to secondary hazards (ground failures, tsunami, fire following) on the building stock, critical infrastructures and environment and to estimate the socio-economic impact (e.g. human casualties, economic loss). Data and outcomes from reconnaissance studies are highly critical to enhance the

understanding of earthquake-induced direct and indirect consequences. Despite this, never before an effort was made to collate reconnaissance data into a standardised database.

Empirical data and observations on earthquake-induced damage to buildings and infrastructures, along with analytical data, are essential to improve the understanding of the seismic performance of structures. Though limited (especially in parts of the world where there have been fewer documented events in the recent past), these data are critical for the development, validation and calibration of risk and loss models and for mitigation planning. The utility of existing global data can be further and substantially improved by the aggregation of widely dispersed and variable format data sets into a formal database and by the use of a specific and uniformly agreed data taxonomy.

After a brief presentation of the GEMECD's characteristics and structure (Section 2), the paper will focus on New Zealand's contribution to the GEMECD database which consisted in the analysis of: 4 events localised in the South Pacific area, (namely Newcastle, 1989; Luzon 1990; South of Java 2006; and Samoa Islands 2009); and 3 NZ-specific events, namely Edgecumbe (1987), Darfield (2010) and Christchurch (2011). Particular focus will be given to the Darfield and Christchurch earthquakes, for which the damage and impacts on the built-environment have been, so far, surveyed and collated in various databases "owned" by different agencies and research institutions.

2 THE GEMECD DATABASE

2.1 Data content and typology

The GEMECD gives emphasis on collecting and collating data and studies on building damage induced by ground shaking, being this the first development agenda of GEM's activities. However, the GEMECD aims to have a broader coverage and collect further aspects of earthquake-induced consequences, including: consequences from earthquake-induced secondary hazards (with special focus on geotechnical hazards, tsunami and fire following) on buildings, critical facilities, infrastructures, and lifelines; human casualty studies; and, socio-economic impact as a whole (Fig.1).

The data-sources and study-sources are accurately referenced within the GEMECD and, when possible a web link to the original data source or study is provided along with accompanying comments. All the data imported into the GEMECD are geo-coded (whether a town district or neighborhood, a village or an intensity zone, or the punctual or linear representation of an asset) as accurately as possible. The data are standardised and harmonised according to GEM Risk definitions and the GEM Ontology and Taxonomy (Brzev et al. 2013; Gallagher et al. 2013).

2.2 GEMECD Structure

A tier structure composed by four consecutive tiers (Tier 0 to Tier 3) is used to collect and present the earthquake consequences data (Fig. 1).

Tier 0: At the top tier, a homepage shows a global map indicating epicenters of all the earthquakes and their list by year of occurrence, event name and country. The database uses digital maps, which can be viewed at the desired scale, in standard modes – road map, terrain map, or satellite image.

Tier 1: By selecting one of the events in Tier 0 the user is taken to Tier 1. Tier 1 contains the event overview, including: seismological data of the earthquake; a brief event narrative; casualty data (number of dead, injured, missing people); data on homelessness; building damage (building and dwelling units severely damaged and destroyed); economic loss (direct, indirect); and, insured loss. The event overview is available for all the earthquakes contained in the database. The quantity of data reported is subject to the data availability. Links to a literature database for each event and the graphical overviews of the data will be provided in the near future. To ensure uniformity and comparativeness, seismological data are obtained from the USGS ShakeMap Atlas (e.g. moment magnitude and focal depth) and USGS EXPO-CAT (Allen et al. 2009) database. Any relevant discrepancy with seismological data provided by other acknowledged agencies is reported in the comments. Consequence data (e.g. casualties, damage, homelessness and economic loss) are obtained via an exhaustive literature review from local databases and acknowledged sources (official reports,

papers in peer review journals etc.). Data source is referenced in the source field and comments are provided when different values exist in the literature.

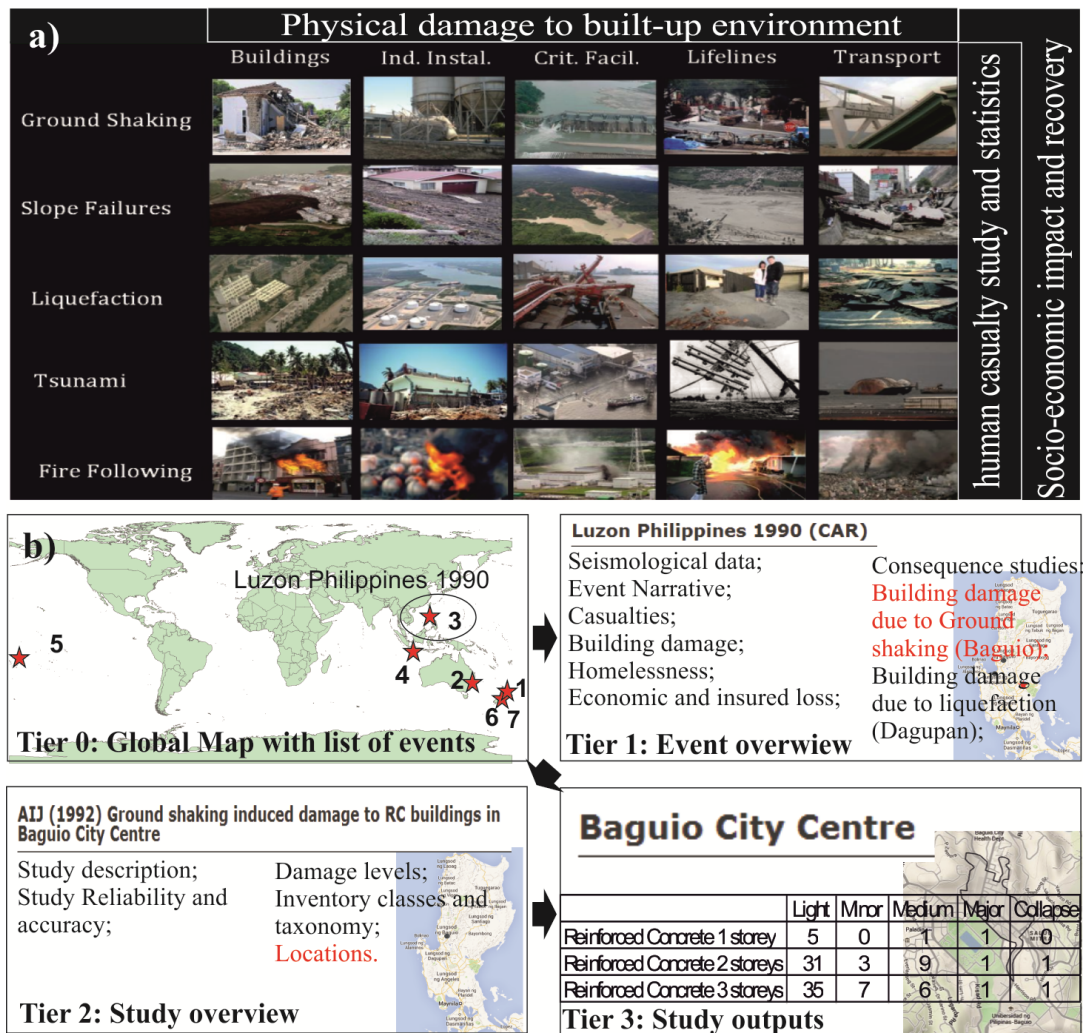


Figure 1. GEMECD framework: a) earthquake consequences matrix (modified from Pomonis & So, 2012; So et al., 2012); b) GEMECD tier structure.

In Tier 1 the USGS ShakeMap of the event is provided (the original ShakeMaps have been improved by USGS, for most of the events contained in the GEMECD) to spatially relate the consequences collected in the GEMECD to ground motion intensity levels. For the events that include consequence studies due to secondary and induced hazards further maps may be included, depending on their availability, e.g.: landslide outline, liquefaction outline, tsunami inundation and fire affected area. For simplicity, only the consequences induced by the most dominant secondary hazard are included in the event description, e.g.: tsunami inundation for the 2006 South of Java, Indonesia; landslides for the 2008 Wenchuan, China earthquake; liquefaction for the 2010 Darfield and the 2011 Christchurch earthquakes in New Zealand, etc.. Within Tier 1 the available consequence studies, for the selected event, are listed.

Tier 2: By selecting one of the consequence studies listed in Tier 1 the user is taken to Tier 2. For each consequence study an overview is provided along with a judgment on the study reliability and accuracy (exception made for the socio-economic impact and recovery studies). The reliability and accuracy rating is based on three components, namely: study quality, documentation quality and location accuracy. A superior, average or marginal rating is assigned based on pre-defined criteria. Justification for the assigned rate is provided in the comment section.

Detailed data are provided in a different format depending on the specific study. As an example, if the study reports on ground-shaking-induced damage to buildings, details are provided on: damage scale adopted to qualitatively describe the damage; building inventory classes and structural typologies; the number of buildings surveyed; a link to a glossary of images describing each structural typology included in the study; possibly, a bar chart summarising the observed damage data. Studies on ground-shaking induced building damage are available for all the events included in the database exception made for those where the ground shaking did not cause damage (e.g. South of Java 2006, Samoa 2009)

Tier 3: The selection of a survey location brings the user to the final tier, Tier 3, where the individual survey data for a particular location are presented. The survey data can be aggregated at a different administrative level (e.g. region, village, neighborhood etc.), that is specified in the study overview, namely Tier 2. At Tier 3 the user will access a matrix summarizing the study outputs. As an example, as far as building damage due to ground shaking or secondary induced hazard is concerned, the data are reported by building inventory classes or taxonomy groups (i.e. construction type, number of storeys, date of construction etc.) and damage levels. In the case of casualty studies data are reported by casualty level, namely: uninjured, injured, missing and dead.

To each building inventory class is associated a string obtained through the application of the GEM building Taxonomy to it. The locations can be any of three forms of geocoding i.e. a single geo-coordinate, an administrative boundary (using the Global Administrative Areas database, GADM) or a user defined boundary shape file, that shows the contour of the survey area, when this is available. The locations map is accessible via the Map of Locations facility of the database.

3 THE NEW ZEALAND CONTRIBUTION

New Zealand is contributing to the GEMECD with 7 studies out of the 71 events of the database, namely: 1) the 1987 Edgecumbe earthquake (New Zealand); 2) the 1989 Newcastle earthquake (Australia); 3) the 1990 Luzon earthquake (Philippines); 4) the 2006 South of Java earthquake (Indonesia); 5) the 2009 Samoa earthquake (Samoa, American Samoa and Tonga); and the recent New Zealand earthquakes, namely 6) the Sept. 4, 2010 Darfield, and 7) the Feb. 22, 2011 Christchurch earthquakes.

Table 1. List of events and earthquake consequence studies performed as part of the New Zealand contribution to GEMECD.

Tier 0			Tier 1	Tier 2			
<i>Event Name</i>	<i>Country (-ies)</i>	<i>YEAR</i>	<i>Event Overview (N=7)</i>	<i>Building Damage due to ground shaking</i>	<i>Human Casualties</i>	<i>Observational data-info on damage to critical facilities & infrastructure</i>	<i>Observational data-info on liquefaction, tsunamis, fire following, fault rupture</i>
Edgecumbe	New Zealand	1987	x	x*		x	
Newcastle	Australia	1989	x	x			
Luzon	Philippines	1990	x	x			x (Liquefaction)
South of Java	Indonesia	2006	x		x		
Samoa	Samoa	2009	x				x (Tsunami)
Darfield	New Zealand	2010	x	x		x	x (Liquefaction)
Christchurch	New Zealand	2011	x	x	x	x	x (Liquefaction)

*Tier 3 is accessible by selecting one of the locations available at Tier 2.

To date, the event overview (Tier 1) has been completed for all the 7 earthquakes. Specific studies (Tier 2) completed at date include: the building damage due to ground shaking for all the events (exception made for the South of Java and Samoa earthquakes, where earthquake consequences due to ground shaking were negligible); the human casualty studies for the South of Java and Christchurch earthquakes; the damage to critical facilities and infrastructures for the three New Zealand events; and, finally, the damage to buildings due to secondary induced hazards for the 1990 Luzon (liquefaction), 2009 Samoa (tsunami), 2010 Darfield and 2011 Christchurch (liquefaction) (Table 1).

The GEMECD represented an opportunity for collating, comparing and reviewing existing databases created by different teams following the Darfield and Christchurch earthquakes and for uniformising them into a standardised database including data and information on: damage to standard-buildings (aggregated) and critical buildings or infrastructures (e.g. bridges, water system) due to ground shaking and liquefaction; human casualties (for 2011 Christchurch earthquake).

In the following sub-sections a brief description of each analysed event and the outputs from a specific consequence study (Tier 3 level) is presented.

3.1 The March 2, 1987 Edgecumbe Earthquake (Mw 6.5), New Zealand

The earthquake struck the Bay of Plenty Region of New Zealand (northern part of New Zealand's North Island) on the afternoon of Monday, March 2, 1987. It had a moment magnitude (Mw) 6.5 and focal depth of 8 to 15 km (depending on reporting seismological agency). Despite the vigorous ground shaking produced no deaths were associated to the earthquake mainly due to low population density and the occurrence of a foreshock few minutes before the main shock. The damage to the built environment occurred mainly due to ground shaking and liquefaction phenomena at localized sites. The reporting of specific studies considered for the Edgecumbe earthquake (Tab 1) has not been completed yet but will be available in the near future.

3.2 The December 28, 1989 Newcastle Earthquake (Mw 5.4), Australia

The earthquake, 5.4 Mw, struck the east coast of Australia (New South Wales) on December 28, 1989. It caused severe damage to the built environment and 12 deaths (plus one person that died due to heart attack caused by the earthquake). Ground shaking with localized site effects due to the presence of soft soils was the main responsible for the widespread damage.

The specific consequence study, namely building damage due to ground shaking, is based on the field study by the EEFIT team (Pappin et al., 1991) that carried out a damage survey in two of the hardest hit areas of Newcastle City inspecting 625 buildings. A point coordinate calculated at the mean distance between the surveyed locations has been considered to represent the study location (the areas are sufficiently close to each other so that no significant differences in ground shaking were detected).

Table 2. Building damage due to ground shaking in Newcastle (Pappin et al., 1991) as reported in GEMECD, Tier 3. The building inventory classes are grouped by primary construction type and building use.

	D0	D1	D2	D3	D4	D5
Unreinforced Masonry Commercial	173	40	24	27	5	0
Unreinforced Masonry Residential	45	12	7	3	0	0
Reinforced Concrete Commercial	105	11	9	4	0	0
Timber Commercial	19	1	1	0	0	0
Timber Residential	63	1	12	0	0	0
Total*	405	65	53	34	5	0

* some of the buildings are excluded from the matrix either because belonging to small samples (not statistically valid) or because missing in attributes necessary to be part of one of the building inventory class.

To the study a superior rating for data and documentation quality and an average rating for the location accuracy has been assigned.

3.3 The July 16, 1990 Luzon Earthquake (Mw 7.7), Philippines

The earthquake (7.7 Mw) struck northern and central Luzon, the largest and most heavily populated island of the Republic of Philippines on July 16, 1990, at 4:26 pm local time, resulting in widespread damage and loss of lives. Damage resulted by the combined effect of primary (ground shaking) and secondary induced hazards (liquefaction, landslides, surface rupture). The consequence study for this event refers to the building damage (aggregated data) induced by ground shaking in Baguio City, Philippines and is based on a field reconnaissance carried out by the Architectural Institute of Japan, AIJ (AIJ, 1992). The AIJ team inspected 181 reinforced concrete buildings (grouped by storey numbers). Table 3 reports an extract of the damage matrix. A superior rating is assigned to all the study rating fields, namely: data quality, documentation quality and location accuracy. An additional study of damage to buildings due to liquefaction in Dagupan City has also been implemented.

Table 3. Extract of the building damage matrix due to ground shaking in Baguio city (AIJ 1992) as reported in GEMECD, Tier 3.

	Light and no damage	Minor damage	Medium damage	Major damage	Collapse (partial or total)
Reinforced Concrete 1 storey	5	0	1	1	0
Reinforced Concrete 2 storeys	31	3	9	1	1
Reinforced Concrete 3 storeys	35	7	6	1	1

3.4 The July 17 2006, South Of Java Earthquake, Indonesia

On July 17, 2006 a Mw 7.7 earthquake occurred offshore, south-west of Java, Indonesia. The ground shaking was only weakly felt by some of the people living in Java and did not cause damage or casualties. However, the earthquake generated a large tsunami which had a catastrophic impact on localities along the southern-west coast of the Island of Java including significant loss of lives. The consequence study for this earthquake investigates the human casualties (deaths, injuries and missing people) that occurred in the regency of Ciamis at village/site level (Table 4). The study is based on data collected by civil authorities in Ciamis reported in the paper of Reese et al. (2007). A sample of the casualty study is shown in Table 4. For this study a superior rating is assigned to the documentation quality whereas an average rating to the data quality and location accuracy.

Table 4. Extract from the casualty study for the village of Pangandaran, Kalipucang district, West Java (Reese et al. 2007) as reported in GEMECD Tier 3.

Location name	Total Uninjured	Total Injured	Total Killed	Total Missing
Pangandaran	9.117	5	41	0

3.5 The September 29, 2009 Samoa and American Samoa Earthquake (Mw 8.0)

The earthquake (Mw 8.0) occurred in South Pacific on Tuesday September 29, 2009 and triggered a large tsunami that affected the islands of Samoa, American Samoa and Tonga's Niua group causing widespread damage and numerous casualties. The ground shaking was consciously felt by people living in the areas subsequently inundated by the tsunami, however it was not strong enough to produce damage to the buildings. One of the earthquake consequence studies investigates the damage to buildings (aggregated by construction class) due to tsunami. The study is based on the damage survey carried out by a reconnaissance team from New Zealand in Samoa (Upolu Island) and American Samoa (Tutuila Island) (Reese et al. 2011), which investigated, among others, 120 masonry residential buildings in Samoa and American Samoa. The damage statistics for the Island of Tutuila

are reported in Table 5.

Table 5. Extract from the damage to masonry residential building matrix, during the American Samoa tsunami (Reese et al. 2011) as reported in GEMECD Tier 3.

	None	Light	Minor	Moderate	Severe	Collapse
Masonry Residential	10	6	8	14	12	34

An average rating is assigned to all the fields (data quality, documentation quality, location accuracy) of the study reliability rating system.

3.6 The September 4, 2010 Darfield Earthquake (Mw 7.0)

The Darfield earthquake (Mw 7.0) struck the Canterbury Region of New Zealand (~40 km west of Christchurch) at 4.35am local time of September 4, 2010. The event, felt throughout New Zealand, generated ground motion up to 1.26g (vertical component) with several readings well over 0.5 g in the areas near the fault rupture. The earthquake induced widespread liquefaction phenomena in Christchurch, which caused extensive damage to buried lifelines (in particular water and wastewater pipelines), residential housing and other buildings, and to a lesser extent to roads, railroad, bridges, embankments and levees. Table 6 presents an example of one of the study available for the Sept 4, 2010 Darfield earthquake which reports a detailed description (asset by asset) of the damage suffered by 11 churches located in Christchurch-Darfield area (Anagnostopoulou et al. 2010). A superior rating is assigned to all rating fields: data quality, documentation quality and location accuracy.

Table 6. Example of damage to churches output (Anagnostopoulou et al. 2010) as reported in GEMECD Tier 3

Class	Type	Name	Date of Construction	Asset location	Lat	Long	Detailed damage description
Historic Building	Church	Christchurch Cathedral	1864-1881	100, Cathedral Square	43.531	172.637	Insignificant damage. The only damage was to ornamental stone details.

Further consequence studies related to the Darfield earthquake are ongoing, aiming to include in GEMECD standardized data on: ground-shaking induced damage to residential buildings (aggregated data); ground-shaking and liquefaction induced damage on lifelines (i.e. water systems, Knight et al. 2012) and critical infrastructures (i.e. bridges, Palermo et al. 2010).

3.7 The February 22, 2011, Christchurch Earthquake (Mw 6.1)

The Christchurch earthquake (Mw 6.1), occurred ~10 km south-east of Christchurch City on February 22, 2011, at 12.51 pm local time. The earthquake produced exceptionally high values of ground shaking up to 2.2 g (vertical component) with another two readings beyond 1 g, extensive slope failures (landslides and rock falls) and widespread liquefaction. Liquefaction accounted for most of the damage occurred to lifeline systems and residential buildings.

Table 7 presents a sample of one of the consequence study available in for the Christchurch earthquake, namely the casualties study, providing the individual location of the 185 deaths, the cause of death (i.e. building collapse, falling masonry etc.) and whether they occurred indoors or outdoors. The study is based on the integration of the data reported by: the local press (STUFF.CO.NZ 2013); New Zealand Police (NZP 2013); and, the Canterbury Earthquakes Royal Commission Report (CERC 2012).

Table 7 Individual location of 133 of the 185 deaths due to the Christchurch earthquake.

Location name	Total killed	Remarks
Canterbury Television (CTV) Building	115	115 people died due to the CTV building collapse. Indoors.
Pyne Gould Corporation (PGC) Building	18	18 people died due to the PGC building collapse. Indoors.

A superior rating is assigned to all the study rating fields: data quality, documentation quality and location accuracy. Further consequence studies related to the Christchurch earthquake are on-going, aiming to include in GEMECD standardized data on: ground-shaking induced damages to standard buildings (aggregated data); consequence of ground shaking and liquefaction on lifelines (i.e. power system, water, waste water), critical infrastructures (i.e. bridges) and historical buildings (i.e. churches).

4 CONCLUSION

The NZ contribution to GEMECD represents an opportunity for collating, comparing and reviewing documents and data reporting on earthquake-induced consequences and for uniformising them into a standardised database. By the end of March all the earthquake consequence studies intended for the Darfield and Christchurch earthquakes (see section 3.6-7) will be available on the GEMECD platform. At the end of the project the scientific board of GEM, GEM partners, and NZ researchers, councils, local and other government authorities who collaborated and contributed to the GEMECD activities will have access to empirical data that can support and inform seismic risk analysis and seismic risk mitigation planning.

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