16th World Conference on Earthquake Engineering, 16WCEE 2017
Santiago Chile, January 9th to 13th 2017
Paper N° 170
Registration Code: S-Y1461823824

THE GLOBAL ROLE OF EARTHQUAKE FATALITIES IN DECISION-MAKING: EARTHQUAKES VERSUS OTHER CAUSES OF FATALITIES

J.E.Daniell(1), A.M. Schaefer(2), F. Wenzel(3), H-H. Tsang(4)

1) *Natural Hazards Risk Engineer & John Monash Scholar (Dr.-Ing.), Geophysical Institute & Center for Disaster Management and Risk Reduction Technology, Karlsruhe Institute of Technology, Germany, e-mail address: j.e.daniell@gmail.com*
2) *PhD Candidate (Dipl.-Ing., MSc.), Geophysical Institute & Center for Disaster Management and Risk Reduction Technology, Karlsruhe Institute of Technology, Germany, e-mail address: andreas.schaefer@kit.edu*
3) *Professor & Head of Geophysical Institute, Geophysical Institute & Center for Disaster Management and Risk Reduction Technology, Karlsruhe Institute of Technology, Germany, e-mail address: friedemann.wenzel@kit.edu*
4) *Senior Lecturer in Structural Engineering (Dr.), Swinburne University of Technology, Australia, e-mail address: htsang@swin.edu.au*

Abstract

Earthquakes have caused over 2.3 million fatalities since 1900. They have also been responsible for the equivalent loss of over $1.25 trillion USD of human capital derived economic effects in total across the globe from casualties. However, a key consideration for decision-makers implementing earthquake sensitive design in different countries around the world is the risk of an earthquake death compared to other types of deaths in their country. Additionally, the role of life safety is increasing, with risk-based earthquake resistant codes becoming more commonplace.

On an annualised level, very few countries show earthquakes to be one of the highest probability methods for death. However, in particular years with large events these totals can easily exceed the total death count for a particular country. An example of this is Haiti, with the equivalent earthquake death rate in 2010 exceeding the total death rate in the country due to all other causes. In this study, various methods of analysis are undertaken for earthquake fatalities from around the world to show trends and the relative importance of earthquake effects.

In this paper, the creation of empirical annualised ratios of earthquake fatalities from the year 1500 onwards vs. other methods of fatalities (cancer, floods, diseases, accidents etc.) for each country using the CATDAT damaging earthquakes database is undertaken. In this study, around 50 countries have been shown to have at least one single earthquake event year exceeding that of all traffic fatalities, and 15 countries have higher than the equivalent total death rate of the country. On a province level, the number of countries having such an event significantly increases. Next, the production of stochastic based analysis derived annualised ratios of earthquake fatalities using the CATDAT rapid fatality estimation methodology is examined to shows the inherent risk in countries, such as Australia, building from low earthquake-resistant double brick and brick veneer construction.

Using the stochastic risk assessment methodology, the production of F-N (fatality vs. probability of exceedance) curves for earthquake fatalities vs. other types of disasters for an example from Eastern Europe and Central Asian countries as well as a comparison with existing codes are shown. These F-N curves provide decision-makers with a tool to inform an equivalent evaluation of risk from mortality causes that occur on a reasonably constant level (cancer, traffic accidents etc.) vs. sporadically high death rates (natural disasters, pandemics etc.) by taking a view of temporal risk. This tool for disaster mitigation decisions as well as a historical analysis, stochastic analysis and the value of life are discussed for future decision-making purposes.

Keywords: micromorts, earthquake fatalities, global risks, life insurance, cost-benefit

1. Introduction

The “recall ability” of a disaster is also extremely important for improving the level of political willingness to act and reduce deaths in future events [1]. If a disaster has just occurred or is memorable, governments are willing to invest money in retrofitting and improving to a better standard (e.g. Christchurch 2011 – [2]); however, with time, this willingness decreases, as other causes of death, impacts, worldwide events and everyday economic decisions take over in the minds of the public.

A hypothesis is that with better metrics to recognise the risk of being killed in an earthquake, an improvement in the ability of governments to invest in improved safety will occur. This paper sets out to explore the trends and reality of earthquake fatalities as a key to life safety by exploring the quantity of a micromort in annual terms from earthquakes vs. other disaster types, and then explore the applicability of F-N (fatality vs. return period) curves as tools for disaster mitigation decisions vs. other types of disasters for various countries. These F-N curves provide decision-makers with a tool to compare an equivalent evaluation of risk from mortality causes that occur on a reasonably constant level (cancer, traffic accidents etc.) vs. sporadically high death rates (natural disasters, pandemics etc.) by taking a view of temporal risk. [3] presented F-N curves for the purpose of China, and in this paper a view of Central Asia and Eastern Europe will be examined.

However, earthquakes and other disasters generally do not discriminate with respect to age (with the exception of tsunami), compared to many other death types; thus each death in adjusted life years is often a lot more from an earthquake compared to other deaths. This is an important concept that needs to be taken into account when comparing disasters with normalized death rates. In addition to historical studies, the production of stochastic based analysis derived annualised ratios of earthquake fatalities using the CATDAT rapid fatality estimation methodology [4] to fill in the gaps of low seismicity countries, and the demographic changes from previous events to today’s population, are examined for certain countries. This shows the inherent risk in countries with a lack of historical record of large earthquakes, such as Australia, building from low earthquake-resistant double brick and brick veneer construction. The disaster data and population data per country from CATDAT ([5]; [6]) for floods, earthquake, storms, volcanoes, landslides, drought/temperature have been used.

2. Historical Earthquake fatalities as a basis for decision-making

2.1 Trends of historical earthquake fatalities

An examination of fatalities since 1500 has been undertaken, with over 5.3 million fatalities being found and recorded from 3300+ fatal earthquakes. The earthquake risk of countries is explored by examining the largest global historical damaging earthquake database, CATDAT, which includes not only the historical loss estimates of over 15,000 damaging earthquakes (9800+ since 1900) and footprints of most earthquakes, but also socioeconomic indicators through time, such as the population, human development, economic inflation estimates and other key characteristics allowing for the trends of earthquakes to be examined. The death toll from each of the damaging earthquake years from 1900-2015 included in the CATDAT database have been used to form the following temporal trend of disaster losses as seen in Figure 1. When deaths are classed via human development index since 1900 [5], we can see that as the world has evolved, this has not necessarily translated in reduced absolute fatalities. Over the period from 1900-2015, the global population as well as the global death rate have been examined, taking into account war and disaster deaths as well as all non-disaster related deaths. Through this, long term averages of earthquake deaths from nearly 2200 fatal events as a percentage of worldwide deaths and population have been examined. Earthquakes have caused over 2.32 (2.18-2.73) million fatalities since 1900. They have also been responsible for the equivalent loss of over $1.25 trillion USD of human capital derived economic losses and $3.5 trillion USD economic costs in total across the globe. By using a 10-year average in terms of yearly earthquake deaths worldwide, the general trend of earthquake deaths per year as a percentage of total global deaths can be seen. The death rate is affected by the major events and is periodic but can be seen to be reasonably constant as a percentage of global deaths per year, indicating that the earthquake death rate follows the death rate from other causes such as medical advances and reduced death tolls in major wars and epidemics, meaning that better building practices are having some impact. The death rate from all causes worldwide reduced as the average life expectancy was increasing worldwide. A range of 46.8 to 77.9 million deaths per year is seen globally, with a maximum in 1918 and minimum in 1977.

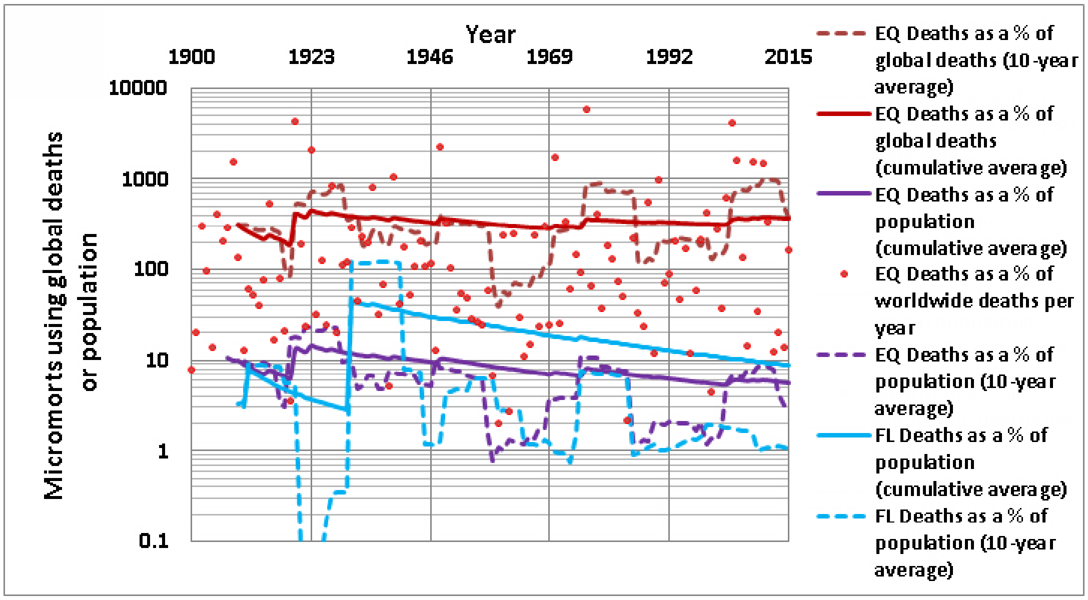

Fig. 1 – Yearly one in a million chance of death as a proportion from a) earthquakes vs. population - purple; b) earthquakes vs. global deaths (micromorts as a proportion of deaths) - red [6]; c) floods vs. population – blue

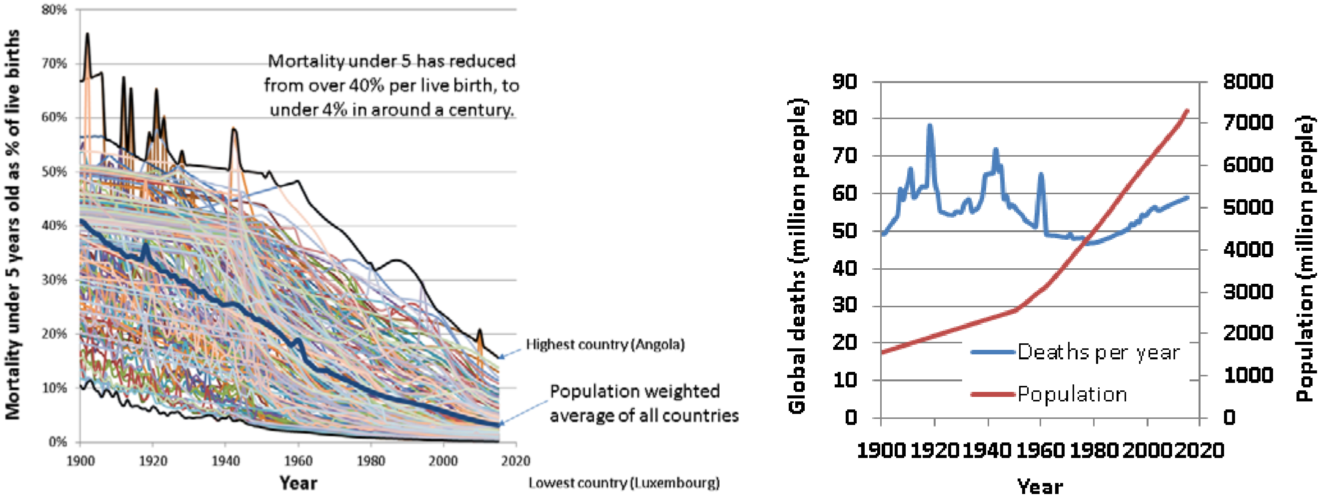

Fig. 2 - Left: Child mortality per country (adapted from [7]); Right: No. of global deaths and population from 1900-2015 [6]

Although the 10-year average was increasing with the 2004 Indian Ocean Tsunami, 2008 Sichuan earthquake and the 2010 Haiti earthquake, the last 5-year period since 2011 has been one of the quietest on record, meaning a current return to the long term average (ca. 11,000 deaths in total vs. an expected 100,000 in this time period). As shown in Figure 1, as a percentage of global population, the death rate from earthquakes has also seen to be decreasing, meaning that with increasing life expectancy (and decreasing child mortality – Figure 2), an improvement in fatality rate is also observed. Similarly, flood has also decreased from large events seen in the early part of the century (but records are likely incomplete pre-1930). Apart from the large 1975 Banqiao Dam disaster, flood deaths show a lower micromort 10 year average than earthquake since around 1960 with around 1 micromort currently (close to the tolerable limit as shown later in the paper).

The 1556 Shaanxi earthquake, with a reported 830,000 deaths (most due to loess cave building collapses), is often seen as the highest death toll from an earthquake in historical records since 1500. As a percentage of the population of the world (ca. 478-710 million people with an average of 523 million people in the globe), this was around 0.16%. As a % of global deaths at the time (approx. 24.9 million deaths in 1556), this was close to 3.2% of all deaths in the year (Table 1). In contrast, since 1900, no year has recorded over 1% of global deaths due to earthquake. Of course, in certain countries, the 1% rate has been exceeded e.g. in Turkmenistan in 1948, or possibly Haiti in 2010 (upper bound 160,000 deaths would indicate 1.6% of the population). The 1556 event as a disaster has only ever been outdone by famine and drought in the last 500 years, with the 1931 floods in China coming at a time where the population was already around 2.1 billion, thus coming close to the 1556 event with a 0.13% death rate globally. The volcanic eruption of Tambora in the 1815 year without a summer, along with the ensuing famine across the globe, caused a high proportion of deaths: however, compared to famine events in 1907, 1911, 1918, 1932 across the globe, this value is not extraordinary.

Table 1 – The most fatal yearly death rate vs. population from earthquake years since 1900.

Year	Global deaths (mn ppl)	Population (mn ppl)	Earthquake Deaths	% of global deaths
1556	22.4	523	832330	3.72%
1976	48.2	4158	284222	0.59%
1920	63.2	1961	276133	0.44%
2004	55.3	6387	229136	0.41%
1667	28	644	97093	0.35%
1693	29.2	672	93000	0.32%
1721	30.5	717	77555	0.25%
1718	30.2	711	75060	0.25%
1948	56.5	2516	128305	0.23%
1923	55.1	2021	115449	0.21%

*NB: Haiti 2010 is given 80,000 deaths (if the upper bound fatality estimate of 140,000 were used, then 2010 would be 0.297% and No. 7 of all-time; however, the same could be said of other questionable death tolls). [8] shows 111,794 deaths (93,273–130,316) as a median, [9] from 46,190 to 84,961 deaths, [10] shows 63,901 deaths (49,033 to 81,862) using damage level and 74,190 deaths (range: 63,061 to 86,555) using mortality.

2.2 Annualised fatalities per country for earthquakes from historical events

The concept of a micromort is an important tool for the comparison of annualised fatalities from various causes across the globe. It is a relative value, and is the concept that there is a one in a million chance of death. For our purpose, we will define the time period of the micromort as a year and that there is a one death in one million people chance of it happening. This would mean that if an earthquakes in the year 2015 caused 100 deaths in a particular country of 50 million people, the value would be 2 micromorts. Of course, at a different spatial level, the micromort value would have been higher (i.e. within the province where the earthquake occurred); however, we have focused simply on country level statistics for this study.

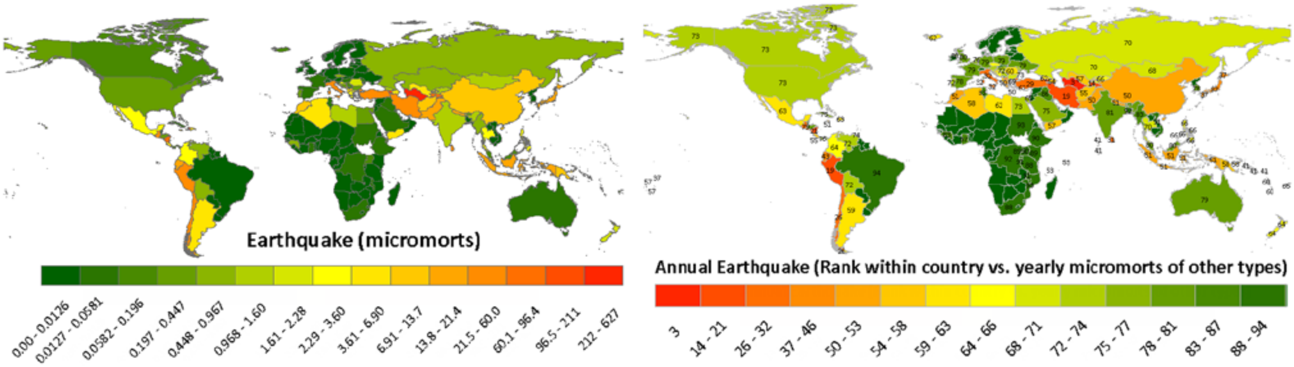

Fig. 3 - Left: Annualised level of earthquake deaths per population measured in micromorts; Right: Country ranking of annualised level of earthquake deaths per population [12]

On an annualised level (Figure 3) given only data from 1900 onwards due to difficulties in collection, very few countries show earthquakes to be one of the highest probability methods of death. In this study, various methods of analysis are undertaken for earthquake fatalities from around the world to show trends and the relative importance of earthquake effects versus other death causes in each country.

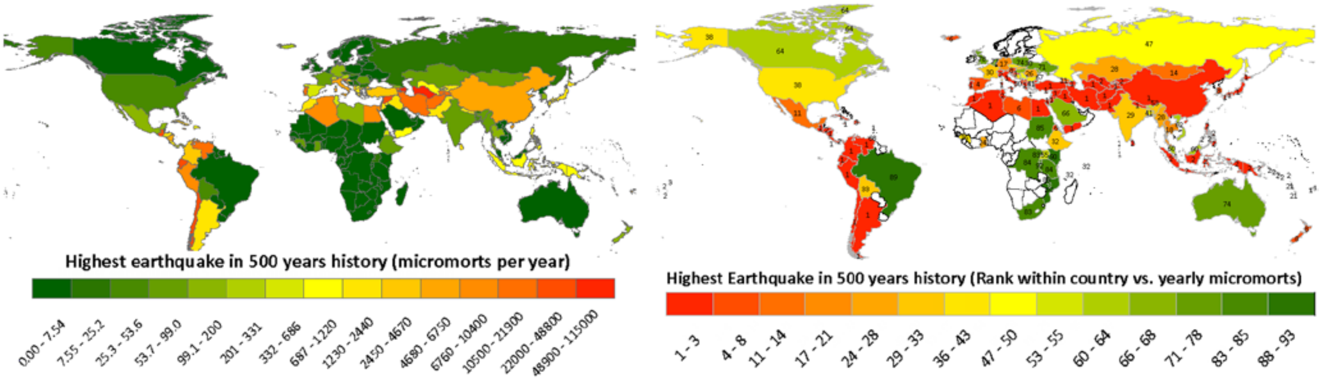

Fig. 4 - Left: Annualised level of earthquake deaths per current population from the highest earthquake year in the CATDAT database in the last 500 years measured in micromorts, Right: Country ranking of annualised level of earthquake deaths per current population from the highest earthquake in the CATDAT database in the last 500 years [12]. (NB. Germany includes death tolls due to 2004 Indian Ocean just to show the effect of the 552 deaths caused in Sri Lanka and Indoneisa etc. – otherwise this would be Rank 70.)

It can be seen that very few countries have earthquakes in the top 50 types of death (Figure 4), showing the low annualised fatality nature of earthquakes vs. more traditional death types. It should be noted, however, that this does not take into account life years left, as otherwise earthquakes would have slightly higher ranks in each country. However, in particular years with large events, these totals can easily exceed the total death count for a particular country. An example of this is Haiti, with the equivalent earthquake death rate in 2010 just higher than the total death rate in the country due to all other causes (using 80,000 deaths as the 2010 death toll – see [11] or [10]). If we take every country and use the highest earthquake death toll as a proxy for fatalities in that country, then using the micromorts in that year vs. all other death causes, the above fatality ranking for earthquake is given within each country as a percentage of 98 different death types. Some countries with little to no earthquake fatalities have been removed from the analysis. It can be seen that over 50 countries have had earthquakes in the last 500 years that have killed more people than other causes of deaths in a single year.

The analysis undertaken does not account for voluntariness of death at this point. [12] and subsequent researchers considered this as a governing parameter in risk acceptability. Referring to Table 2, drug use and alcohol are completely voluntary, whilst driving (road traffic) is somehow neutral and natural disaster event deaths are nearly completely involuntary. Thus, this needs to be taken into account in decision-making.

3. Understanding where earthquakes compare to other disaster and death types

3.1 Annualised fatalities from earthquakes vs. other disaster and mortality causes

Empirical annualised ratios of earthquake fatalities from the year 1500 onwards vs. other methods of fatalities (cancer, floods, diseases, accidents etc.) for each country using the CATDAT damaging earthquakes database have been calculated. A review of data [13] from various Government statistics on traffic and murders [15], [16] has been undertaken for global rates of deaths from murder, traffic, communicable diseases, crime, cancer and other mortality causes as well as for individual countries (Table 2). This has been compared to the population of the country and then derived as a value of micromorts. Thus, the study examines what the highest death types in each country are to examine the apparent risk. In most countries, the life expectancy of a terminally ill patient from one of these diseases differs significantly [17] but is generally much less than in a disaster, whereas the average life years remaining from disaster types have increased significantly from 1960 to 2015, showing the value to be an average of 28 years in 1960, to around 37 years in 2015. This means that each fatality from an earthquake would be at least around 2-4 times more "impactful" than a death from one of these diseases. DALYs (disability adjusted life years) show the years of life lost and the years of disability of the population but these are not often calculated for disaster types. Indeed, [18] has examined the effects from earthquakes in terms of DALYs using the EM-DAT database.

Table 2 – Death types considered in this study for the micromort comparison

Much yearly variation, random	Some variation, Somewhat Random		Constant amount, Non-Random		
Earthquake	Flu & Pneumonia	Maternal	Asthma	Breast Cancer	HIV/AIDS
Storm	Measles	Depression	Endocrine Disorders	Oesophagus Cancer	Hepatitis B
Flood	Meningitis	Suicide	Appendicitis	Stomach Cancer	Hepatitis C
Wildfire	Diarrhoeal	Leishmaniasis	Epilepsy	Liver Cancer	Schizophrenia
Volcano	Hookworm	Trypanosomiasis	Diabetes Mellitus	Colon-Rectum Cancer	Syphilis
Drought/Temp.	Water pollution	Neoplasms	Leprosy	Lung Cancer	Tetanus
Landslides etc.	Indoor pollution	Lung Disease	Oral conditions	Oral Cancer	Chlamydia
Murder	Malaria	Iodine Deficiency	Osteoarthritis	Cervical Cancer	Tuberculosis
Other Injuries	Dengue	Anaemia	Prostatic Hypertrophy	Prostate Cancer	Leprosy
Violence	Encephalitis	Parkinson Disease	Upper Respiratory	Pancreatic Cancer	Leukaemia
Fires	Ascariasis	Drownings	Otitis Media (Ear)	Bladder Cancer	Diphtheria
War	Trichuriasis	Birth Trauma	Pertussis	Ovarian Cancer	Leukaemia
	Schistosomiasis	Vit. A Deficiency	Hypertension	Uterine Cancer	Multiple Sclerosis
	Road Traffic	Peptic Ulcer	Coronary Heart	Skin Cancers	Rheumatoid Arthritis
	Falls	Congenital Anom.	Alzheimers/Dementia	Lymphomas	Inflammatory/Heart
	Malnutrition	Low Birth Weight	Chagas disease	Rheumatic Heart Disease	Liver Disease
			Kidney Disease	Skin Disease	Stroke
			Poisonings	Drug Use	Alcohol

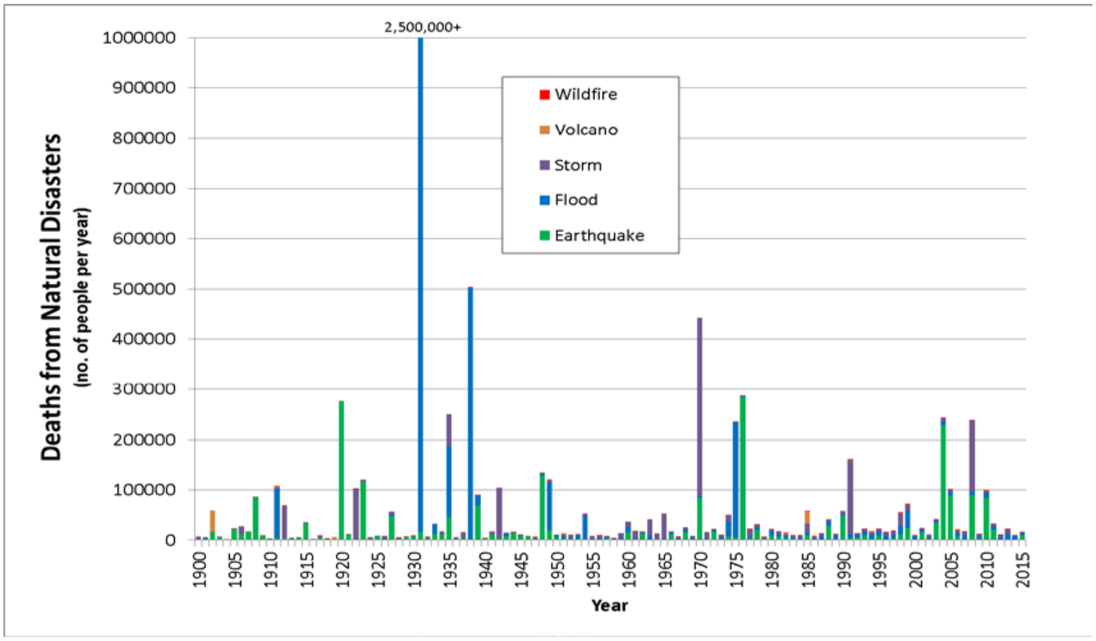

Fig. 5 - Disaster fatalities from 1900-2015 for earthquake (around 43% of deaths since 1960) vs. flood, storm, volcano and wildfire [6]. (NB: Includes floods that were not a "natural disaster", given the blowing up of a dam to impede Japanese advances. However, it is argued that the original dam water was caused by extreme rainfall.)

It should be noted that Haiti finds itself in the top 10 micromorts for earthquake (3rd in 500 years, 2nd per year), 5th in flood, and 5th in storm, showing the risk of the country to natural disasters. In fact, the annual fatality rate from disasters, is higher than the number of murders and traffic deaths combined. From other disaster types, trends from the CATDAT Natural Disasters Database show that earthquakes from 1960 onwards have caused around 43% of all global disaster deaths (Figure 5). Around 40% of these earthquake deaths since 1960 are due to secondary effects rather than shaking. In this study, around 50 countries have been shown to have at least one single event year exceeding that of all traffic fatalities (Table 3), yet very few just based on an average year (Figure 6), and 15 countries have higher than the equivalent total death rate of the country. On a province level, the number of countries having such an event significantly increases.

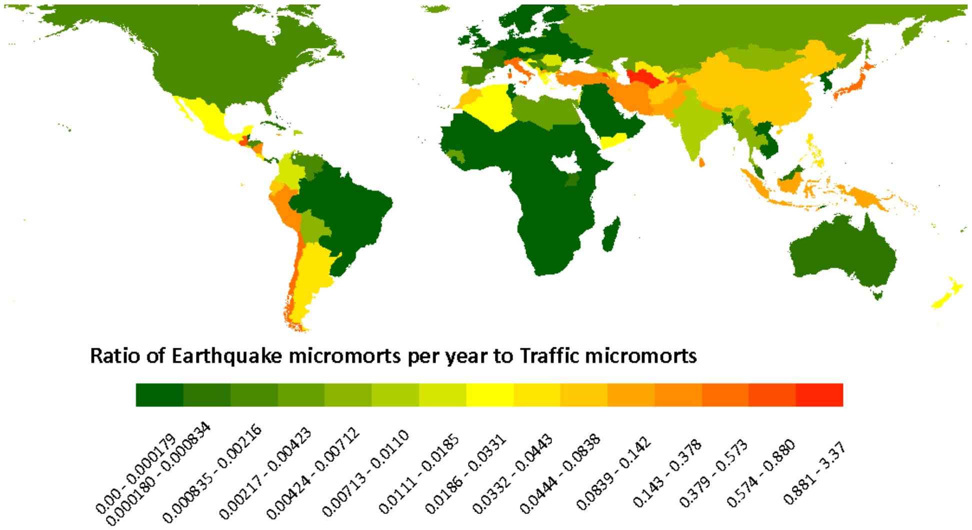

Fig. 6 - The ratio of earthquake micromorts to traffic micromorts in each country [12].

Table 3 – Highest countries in terms of micromorts from disaster types

ISO	Highest EQ in 500 yrs	ISO	EQ	ISO	Flood	ISO	Storm	ISO	Traffic Deaths	ISO	Murder
TKM	22863	TKM	627	GTM	81	BLZ	168	ERI	484	HND	821
AZE	9237	HTI	211	CHN	57	BGD	109	DOM	417	SLV	660
HTI	8422	ARM	159	VEN	29	HND	86	LBY	405	CIV	569
LBN	7695	TJK	96	DJI	13	MMR	65	THA	381	JAM	521
LCA	7262	NIC	70	HTI	11	HTI	41	VEN	372	VEN	490
SVN	4737	PER	60	BGD	9	DMA	31	NGA	337	BLZ	417
CHL	4125	IRN	57	SOM	8	WSM	31	ZAF	319	GTM	414
PRT	2942	CHL	51	BTN	8	VUT	28	IRQ	315	KNA	382
ECU	2752	GTM	51	NPL	7	COM	22	GNB	312	ZMB	380
ARM	2586	LKA	36	TJK	7	FSM	22	OMN	304	UGA	363

3.2 Assigning a value to life for decision-making purposes: earthquake vs. other disaster types.

Assigning a value to life is often one of the only ways of convincing politicians and decision-makers of the need to reduce fatalities, however controversial it is. As part of the work on life costing by [20], an examination of various values of statistical life was undertaken. The reader should refer to this paper for the methodology behind the human capital approach used here. [20] examined the life value using the CATDAT Damaging Earthquakes database, with expected remaining life years and a human capital approach. However, further study is required for the investigation of this effect in the future in terms of the global burden of disease, in order to normalize these annualized fatality rates. One country where there is a lack of data from historical earthquakes is Australia where, due to the limited historical record, very few major quakes have been seen. This therefore makes an interesting case study location when referring to life value. The Newcastle Earthquake in 1989 is the best known earthquakes in Australian history and had 13 fatalities and 160 injuries, and thus around $50 million AUD (1989) in life losses (only around 5% of the total event). However, if the earthquake had occurred when the often-quoted Newcastle Workers' Club had been in full session, the death toll could have been in the order of 200-300; and studies conducted by [19] examined the fact that if the earthquake had occurred 2 months earlier in a time of peak traffic (schools and universities not being on summer holidays), in light of the damage/potential movement of people, there could have been between 700-950 deaths and between 6800-10,000 people injured.

This would have been a cost (not counting the obvious emotional and suffering) equivalent to $2.5-3.2 billion AUD (1989), or far in excess of the insured losses of the event, and approximately the same or exceeding capital stock losses from the event [21].

The losses of a future major earthquake in a low seismicity region show some of the largest potential life cost losses; with that of a Mw6.8 at night in Adelaide, Australia, having around $160 billion USD (current) in life costs (25,000 deaths, 15,000 severe injuries), calculated using the methodology in [20]. Such an earthquake located along a fault line close to the city would cause ground shaking in the order of 0.3g across the city, with local soil effects giving higher values of ground motions [22]. Given the large number of double brick (very vulnerable) and brick veneer structures, catastrophic collapse rates of around 30% or higher would be seen in the near suburbs, with extensive damage also to other building typologies using relationships such as [23] or [24]. Given the heavy structure, fatality rates around 5%-7% would be expected in these collapses, with additional fatalities in other extensively damaged buildings (1.5-3%) [25]. Using these algorithms a value of between 19,000-27,000 fatalities would result. Various studies such as [26] or [27] would give fatality rates of 17.5% or 28% for URM in the near field, which would lead to fatality estimates around 60,000-100,000 for this event (taking lower rates for brick veneer). [28] for New Zealand, gives much lower fatality rates for URM with 6% in collapsed and 0.6% in extensive; this would result in around 15,000 deaths. The 25,000 deaths is calculated through the empirically derived fatality rates from Daniell (2014) and represents around 2% of the population of Adelaide. All fatality methods, however, have much uncertainty, given the lack of historic event data within Australia.

The 2008 Sichuan EQ had $80 billion USD in terms of life cost (deaths and injuries). The 2011 tsunami in Japan was taken into account with age distributions showing a lower life cost than other disasters, given the high percentage of the elderly in the death toll (Figure 7 and 8). A foray into other disasters shows similar calculations of loss for moderate events in very developed nations. [29] estimated the cost of deaths around $2.6m USD in the 1994 Northridge earthquake event (this matches quite well with our estimate of $1.8m USD). Indeed, the total life loss for 33 deaths and the 138 hospitalised people with severe injuries totalled around $120m USD. It was the 24600 hospital cases and the 221000 self-treated people who had a cost of between $1.2 and 2.1 billion USD. In most cases, however, the injury costs are not often taken into account in this detail in other events. These individual event death tolls in each country are then aggregated via the multiplication of the “life loss cost” at the time of the event by the death toll in order to estimate the life loss portion. This is then aggregated in year 2014 dollars to give a reasonable comparison. In the recent Nepal earthquake, the death toll of around 9000 people caused a life value equivalent of around 1.9 billion USD (PPP) (approx. 35% of the reconstruction costs).

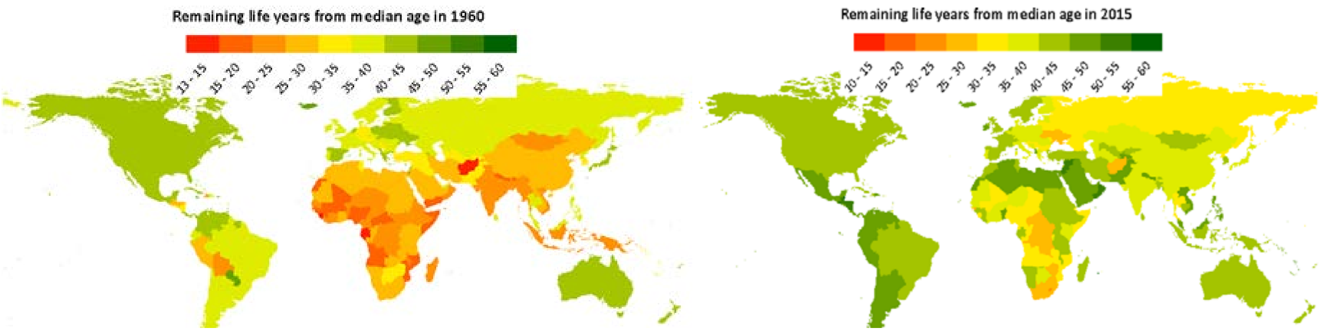

Fig. 7 - Country ranking of annualised level of earthquake deaths per current population from the highest earthquake in the CATDAT database in the last 500 years [20]

When looking at the fatalities and injuries from 1900—2015 in terms of fatalities from earthquakes, much age data is missing. However, by using average distributions in terms of the life expectancy at the time of the event and of the fatalities, a life cost of over $867bn (2014 USD HNDECI adjusted) has been calculated, including injuries, and this value is over $1.35trn (Figure 8). This is approximately 40% of all losses over the same time period. As a percentage of all disaster types, earthquake has caused around half of all life costs. Drought/temperature not included on this diagram has caused around $1.63 trillion USD; however, this data is currently still being collected from over 13 million deaths since 1900.

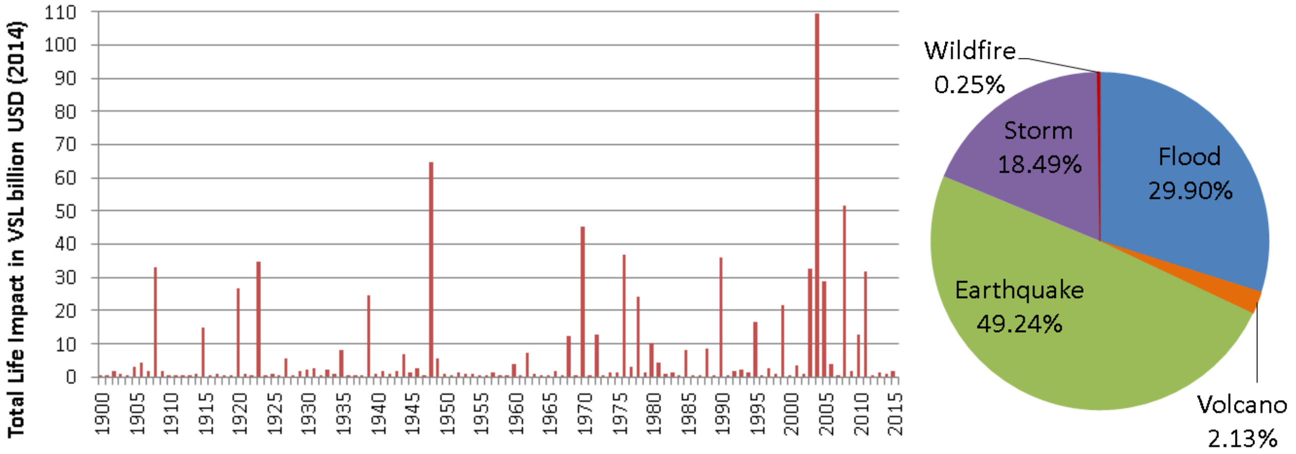

Fig. 8 - Left: Life costs from all earthquakes from 1900-2015 (deaths only) in 2014 USD (given the decrease to 2016, this effect is still being calculated globally) [20]; Right: the proportion of life costs from each disaster type since 1900 totalling $1.72 trn (2014 HNDECI) [6].

A constant distribution for each country is given but the age distribution of earthquake deaths and the influence of VSL needs more study. In terms of injuries, over $450bn (2016 USD) can be counted using the same proportions as in the [30] study; however, it can be seen that authors such as [29] estimate much higher costs where earthquakes occur with a high injury to death ratio (as were likely not counted earlier in the century). This will be added in subsequent studies. Indeed, as a proportion of life costs from other natural disasters, due to the nature of earthquake deaths in the past few decades, the highest proportion comes from earthquake.

3.3 The derivation of F-N curves for earthquakes vs. other disaster types as a proxy for decision-making purposes

The annual frequency of exceedance of a number of deaths is very difficult to often calculate, given the limited record in most places in the world. Stochastic modelling is often needed to calculate these F-N curves.

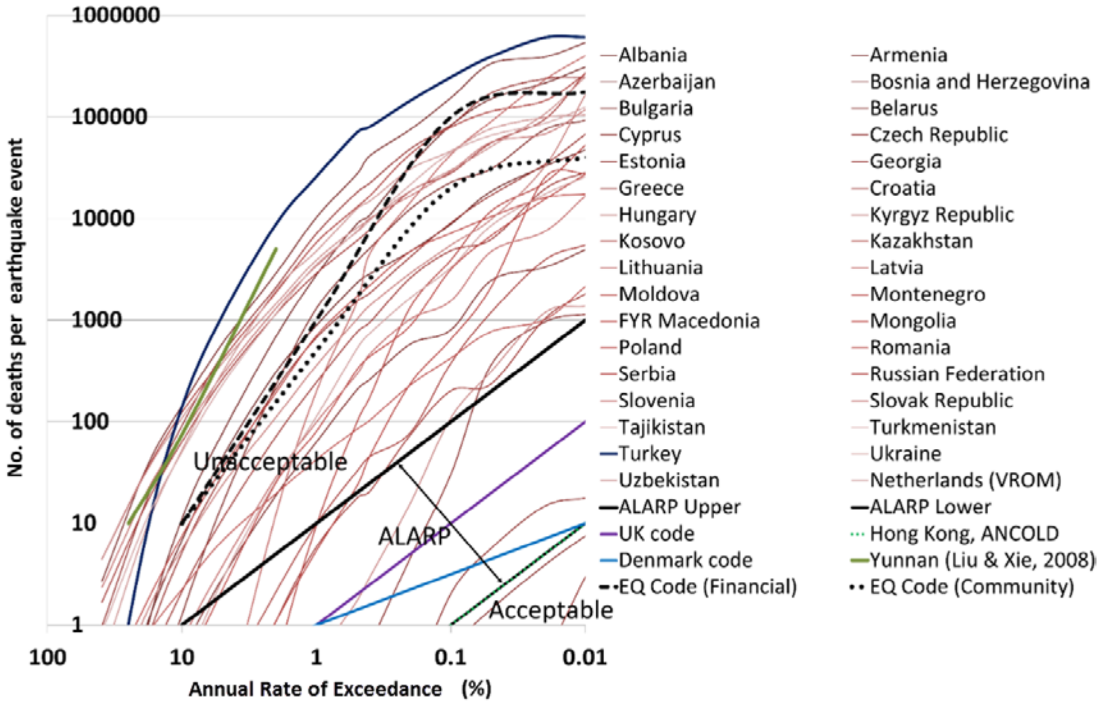

Fig. 9 - F-N curves from various codes and country risk assessments showing acceptability vs. ALARP [20]

Given a limited historic record, e.g. in Eastern Europe or Central Asia ([31]), the historic curves often underestimate (vs. a stochastic curve), given the short historical record seen. However, if there are a few big events of high return period (e.g. the 2010 Haiti earthquake), then this can skew the results. The historical F-N curves can be seen as part of [31].A companion paper to this, [32], examines the application of residual risk limits in codes central to the concept of F-N curves. Governments often are starting to apply a risk-based approach to design, by applying a "As Low As Reasonably Practicable (ALARP) [33]" zone where risk acceptability is taken into account over a country or region as a proxy for design. This is then able to be combined with an annualized approach and life value in order to make a decision as to the risk limit desired by a government and the community acceptance. The unacceptable and acceptable zones change depending on many socio-economic parameters and could be applied in a similar way to a risk index like [34]. [35] and [36] show examples of an F-N curve formed by public jurisdiction and for code purposes. [3] discussed various curves for earthquake, including the actual vs. preferred values for Yunnan F-N curves. Figure 9 gives the example of 34 countries with a potential government ALARP and community ALARP. In this way, it may also be possible to assess the difference between practical and desirable risk. Various standards for hazardous installations around the world (Hong Kong, UK, Denmark, Netherlands) are compared with the ALARPs from infrastructure work. From natural disasters for a country of ca. 100 million people, a potential curve such as that put forward for financial reasons by a government (large black dotted line) vs. a community based F-N curve are shown (small black dotted line).

4. Future implications for decision-making from governments and Conclusions

The scientific basis for decision-making by governments is poorly established when examining disaster losses and need to be developed further. A number of statistical methods have been put forward to characterize the impacts of earthquakes from a human perspective in an attempt to examine metrics that could explain risk to politicians pre-disaster rather than as a reactive system. This includes the comparison of fatality risks across all possible causes, the inclusion of value of life (including the development of accepted standards for this) and the F-N curves (again not commonly done globally).

If we examine the building code changes around the world, these have mostly occurred within a few years of a major earthquake rather than before them. 65 of the 148 code countries [37] have been within 5 years of a major event occurring, showing the reactive nature of governments to improve disaster safety in the ensuing reconstruction phase. That being said, the application of Eurocodes and the former Soviet codes mostly happened without this post-earthquake push. The value of statistical life (economic loss) from various mortality methods, including earthquakes, has been discussed, showing the equivalent impact of earthquakes killing people over a large age range versus other mortality causes that generally impact the elderly. However, a key consideration for decision-makers in different countries around the world is the risk of an earthquake death, compared to other types of deaths in their country, when implementing earthquake sensitive design. Additionally, the role of life safety is increasing with risk-based earthquake resistant codes becoming more commonplace. A tolerable level of individual annual fatality risk of 10^{-6} has been recommended by various organizations, as examined in [38]. It has been shown that a major disaster can far outweigh a yearly risk of death from other death types. However, the annual micromorts per year of disasters are generally an order of magnitude or two lower than some diseases and traffic deaths; therefore decisions needed to protect structures against earthquakes are often taken as a financial decision and retrofitting and other measures are therefore not undertaken. Governments will tend to short-sighted funding given the election cycle, or commit to long-term projects only as an "election promise" [39]. Nevertheless, the level of tolerable fatality risk depends on the public awareness and perception of the associated risk as well as the risks from other hazards and events.

Earthquake fatalities need to be combined with other factors simultaneously in most cases globally if a government is to be convinced to build better. The involuntary nature of disaster deaths needs to be stressed as a greater value has to be placed on these as a result of governmental decision-making. The reoccurring nature of major earthquakes around the world gives a unique chance to put pressure on a "short-term" government during the media phase, as there is also a discussion of how much money to give in aid. This window is often very short and has been examined over the last 7 years by the first author's contribution to Earthquake-report.com, the largest independent website for earthquake information, which shows a greater than 100 times increase in articles globally within 1 week of a major earthquake vs. the background number of articles (ca. 28000/day vs. a background level of ca. 200/day), with many of these not related to the original earthquake or related to local earthquake code matters outside the epicentral area. The fact that capital investment often takes more than 3-5 years, the average length of a politician's time in office, means that earthquake resistant building is often not seen as a high political priority. Given the trend in the number of researchers attending the WCEE, the amount of research into earthquake engineering and its consequences is increasing. However, since governments remain mostly "reactive", most awareness and investment must be made in this post-disaster period to influence earthquake-resistant reconstruction, despite better metrics to present earthquake risk.

5. Copyrights

6. References

[1] Castaños, H., & Lomnitz, C. (2015). High-Tech Risks: The 2011 Tôhoku Extreme Events. *Extreme Events: Observations, Modeling, and Economics*, 214, 381.

[2] Taig, T. (2012). A risk framework for earthquake prone building policy. Wellington: TTAC Limited and GNS Science.

[3] Liu, L., & Xie, L.L. (2008). Research on Acceptable Risk Level for Cities' Ability in Reducing Earthquake Disasters. In *Proceedings of the 14th World Conference on Earthquake Engineering.*

[4] Daniell, J.E., Wenzel F. (2014). "The production and implementation of socioeconomic fragility functions for use in rapid worldwide earthquake loss estimation," Paper No. 490, *15th ECEE*, Istanbul, Turkey.

[5] Daniell J.E. (2014). The development of socio-economic fragility functions for use in worldwide rapid earthquake loss estimation procedures, *Doctoral Thesis*, Karlsruhe Institute of Technology, Karlsruhe, Germany.

[6] Daniell, J.E., Wenzel, F., Schäfer, A. (2016). The economic costs of natural disasters globally from 1900-2015: historical and normalised floods, storms, earthquakes, volcanoes, bushfires, drought and other disasters, *Geophysical Research Abstracts Vol. 18*, EGU2016-1899, 2016

[7] UNICEF, WHO, World Bank (2015). Levels and trends in child mortality 2015, UNICEF Report, 36p.

[8] Kolbe, A.R., Hutson, R.A., Shannon, H., Trzcinski, E., Miles, B., Levitz, N., Puccio, M., James, L., Noel, J.R. and Muggah, R. (2010). Mortality, crime and access to basic needs before and after the Haiti earthquake: a random survey of Port-au-Prince households. *Medicine, conflict and survival*, 26(4), pp. 281-297.

[9] Schwartz, T.T., Pierre, Y-F., Calpas, E. (2011): Building Assessments and Rubble Removal in Quake-Affected Neighborhoods in Haiti, BARR Survey, USAID, LTL Strategies Report.

[10] Doocy, S., Cherewick, M., & Kirsch, T. (2013). Mortality following the Haitian earthquake of 2010: a stratified cluster survey. *Population health metrics*, 11(1), 1.

[11] Daniell, J.E., Khazai, B., Wenzel, F. (2013). Uncovering the mystery of the Haiti death toll, *Nat. Hazards Earth Syst. Sci Discussions*, 1, 1913-1942, 2013. doi:10.5194/nhessd-1-1913-2013.

[12] Daniell, J.E., Wenzel, F., Schaefer, A.M., Tsang, H-H., Daniell, K.A. (2016). Disaster fatalities and their role in government decision-making globally, *NHESS*, in prep.

[13] Starr, C. (1969). Social benefit versus technological risk. *Science* (New York, NY), 165(3899), 1232-1238.

[14] WHO: World Health Organization (2015). World Health Indicators (WHI). Retrieved from: www.who.int/healthinfo/indicators/2015/en/

[15] WBI: World Bank. (2015). World Development Indicators (WDI). Retrieved from http://databank.worldbank.org/data/views/variableSelection/selectvariables.aspx?source=world-development-indicators

[16] Mathers, C.D., Lopez, A.D., & Murray, C.J. (2006). The burden of disease and mortality by condition: data, methods, and results for 2001. *Global burden of disease and risk factors*, 45, 88.

[17] AIHW (2016). Australian Burden of Disease Study: impact and causes of illness and death in Australia 2011. Australian Burden of Disease Study series no. 3. Cat. no. BOD 4. Canberra: AIHW.

[18] Scawthorn, C. (2011). Disaster Casualties – Accounting for Economic Impacts and Diurnal Variation. In: Spence, R., So, E. and Scawthorn, C. (eds), *Human Casualties in Earthquakes*, pp 51-63. Springer.

[19] Hughes, P. (1991). What if the circumstances were different?, *The Macedon Digest*, 6, No.4, Summer 1991/92, p3.

[20] Daniell, J.E., Schaefer, A.M., Wenzel, F., & Kunz-Plapp, T. (2015). The value of life in earthquakes and other natural disasters: historical costs and the benefits of investing in life safety, *Proceedings of the Tenth Pacific Conference on Earthquake Engineering, Building an Earthquake-Resilient Pacific, Sydney, Australia,* 6-8 November.

[21] Daniell, J.E., Schäfer, A., Wenzel F. (2015). "A tail of eight cities: earthquake scenario risk assessment for major Australian cities", *Proceedings of the Tenth Pacific Conference on Earthquake Engineering, Building an Earthquake-Resilient Pacific, Sydney, Australia,* 6-8 November.

[22] Schäfer, A.M., Daniell, J.E., Wenzel F. (2015). The seismic hazard of Australia - a venture into an uncertain future. *Proceedings of the Tenth Pacific Conference on Earthquake Engineering, Building an Earthquake-Resilient Pacific, Sydney, Australia*, 6-8 November.

[23] EQRM: Robinson, D., Fulford, G., & Dhu, T. (2005). EQRM: Geoscience Australia's Earthquake Risk Model: Technical manual: Version 3.0. Commonwealth Government of Australia, http://sourceforge.net/projects/eqrm/files/

[24] Kappos, A.J., Panagopoulos, G., Panagiotopoulos, C., & Penelis, G. (2006). A hybrid method for the vulnerability assessment of R/C and URM buildings. *Bulletin of Earthquake Engineering*, 4(4), 391-413.

[25] Khazai, B., Daniell, J.E., Düzgün, Ş., Kunz-Plapp, T., & Wenzel, F. (2014). "Framework for systemic socio-economic vulnerability and loss assessment". In *SYNER-G: Systemic Seismic Vulnerability and Risk Assessment of Complex Urban, Utility, Lifeline Systems and Critical Facilities* (pp. 89-130). Springer Netherlands.

[26] Coburn, A.W., & Spence, R.J.S. (2002). *Earthquake protection (2nd ed.).* Chichester, NJ: J. Wiley.

[27] Davey, R.A., Shephard, R.B. (1995). Earthquake Risk Assessment study: Study area 1, Wellington City. Wellington: Works Consultancy Services.

[28] Cousins, W.J. (2014). Estimated damage and casualties from earthquakes affecting Auckland. GNS Science Consultancy Report 2013/324.

[29] Porter, K., Shoaf, K., & Seligson, H. (2006). Value of injuries in the Northridge earthquake. *Earthquake Spectra*, 22(2), 555-563.

[30] BTE (2001). Economic Costs of Natural Disasters in Australia, Bureau of Transport Economics Report 103, Canberra. (https://bitre.gov.au/publications/2001/report_103.aspx)

[31] Daniell J.E., Schäfer A. (2014). *Eastern Europe and Central Asia Risk Profiling for Earthquakes*, GFDRR and World Bank, Washington DC.

[32] Tsang, H-H., Wenzel, F., Daniell, J.E. (2016). Residual Fatality Risk Estimates for Setting Earthquake Safety Requirement, *Paper No. 1454*, *Proceedings of the 16th WCEE*, Santiago, Chile, January 9-13, 2017.

[33] Edwards vs. British Coal Ministry (1949). https://en.wikipedia.org/wiki/Edwards_v_National_Coal_Board

[34] Daniell, J.E., Daniell, K.A., Daniell, T.M., Khazai, B. (2010). A country level physical and community risk index in the Asia-Pacific region for earthquakes and floods, *Paper No. 392, 5th CECAR Conference Proceedings*, Sydney, Australia.

[35] Clague, J.J., & Stead, D. (2012). *Landslides: types, mechanisms and modeling.* Cambridge University Press.

[36] Diamantidis, D., Duzgun, S., Nadim, F., & Wöhrle, M. (2006). On the acceptable risk for structures subjected to geohazards. *Geohazards*, June 18-21, ECI Symposium Series, 2006.

[37] Daniell, J.E. (2015). Global View of Seismic Code and Building Practice Factors. In *Encyclopaedia of Earthquake Engineering.* Springer. Beer, M., Patelli, E., Kougioumtzoglou, I. & Siu-Kui Au, I (eds).

[38] Tsang, H.H., Wenzel, F. (2016). Setting Structural Safety Requirement for Controlling Earthquake Mortality Risk. *Safety Science*, 86: 174-183.

[39] ABC PromiseTracker (2016). http://www.abc.net.au/news/2016-05-08/promise-tracker-how-does-the-coalitions-record-stack-up/7379572