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A timeline of the Socio-economic effects of the 2011 Tohoku Earthquake with emphasis on the development of a new worldwide rapid earthquake loss estimation procedure

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Abstract

The 2011 Tohoku earthquake, tsunami and resulting powerplant incident has caused the highest economic loss in history from any earthquake (over $300 billion USD). In addition, it has caused the highest death toll from an earthquake in any developed country (HDI>0.8) by approximately 3 times.

From 2 minutes after the earthquake, earthquake-report.com has followed the socio-economic effects of the earthquake from Japanese and international sources with additional historical input from the CATDAT Damaging Earthquakes Database. In addition, regular updates of the expected social (deaths, injuries, homeless) and economic loss (insured and total) from the corresponding author's worldwide rapid earthquake loss estimation software were given based on the ground shaking and tsunami effects, and then later refined to account for more complex effects.

In this paper, this earthquake and resulting tsunami, the rapid earthquake loss estimation procedures and a comparison with other rapid loss packages are explained. The rapid loss estimation package uses individual country statistics rather than regionalised methodologies.

As part of this study for use in the software, spatio-temporal country-by-country urban-rural building inventories, seismic code and building practice factor indices, global socio-economic indicators, population, HDI, GDP, wage, CPI and normalisation strategies have been created globally from 1900-2011.

Keywords: EQLIPSE, CATDAT, earthquake loss estimation, Tohoku, socio-economic loss.

Introduction

This paper details the methodology and results of the rapid earthquake loss estimation (ELE) procedures detailed in the corresponding author's PhD (Daniell, 2011b). Both of these methodologies are applicable for worldwide use and have been used since late 2009. They are both encompassed within the CATDAT Project under the names, EQLIPSE-Q and EQLIPSE-R. EQLIPSE uses individual country statistics rather than regionalised methodologies and relies on the power of the CATDAT Damaging Earthquakes Database and the related CATDAT social and economic databases of historical information (Daniell, 2003-2011, Daniell et al., 2011d, Daniell, 2010a). As part of this study, for use in the software, spatio-temporal country-by-country urban-rural building inventories, seismic code and building practice factor indices, global socio-economic indicators (HDI etc.), population and normalisation strategies have been created globally from 1900-2011.

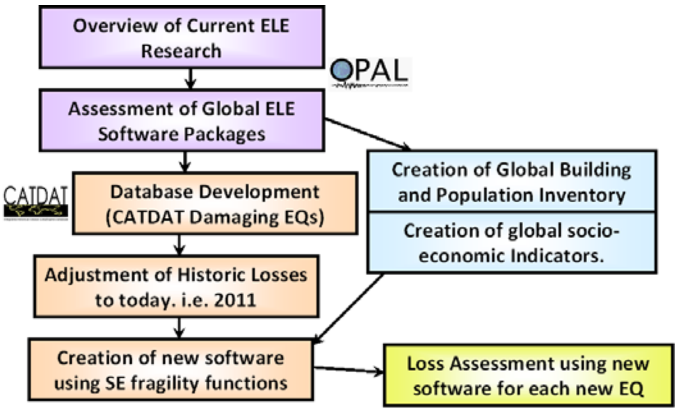


Figure 1: Flowchart of the generalised CATDAT-EQLIPSE Procedure

As part of the OPAL project presented in 2009, over 30 open source ELE software packages around the world were compared in order to determine the best combination for various levels of analysis (Daniell, 2009, Daniell, 2011a). This, combined with the database of historical building, economic and social losses within CATDAT from 2003-2011, provided a good basis for the first normalisation strategy.

Eight other open source worldwide rapid loss estimation procedures were also examined. PAGER has three separate methodologies for earthquake loss estimation as part of their package (empirical, semi-empirical and analytical). ELER has also three methodologies (Levels 0, 1 and 2) but for European countries developed as part of NERIES (Erdik et al., 2008). EXTREMUM uses the QUAKELOSS database resulting from historical Russian databases with the software in use in earthquakes since 1995 (Larionov, 1999, Frolova et al., 2010). WAPMERR (QLARM) is also a rapid loss methodology in place since 2002, using a modified EXTREMUM code and the QUAKELOSS database (Wyss, 2004).

Table 1: Various worldwide rapid earthquake loss estimation software packages.

Name	Database	Vuln. Type	Spatial	Population	Exposure
EXTREMUM	QUAKELOSS	Hybrid	Russian now Worldwide	Point-based	Population+Buildings
QUAKELOSS	QUAKELOSS	Hybrid	Worldwide	Point-based	Population+Buildings
PAGER-Empirical	PAGER-CAT	Empirical	Worldwide	Landscan	Population
PAGER-Semi-empirical	PAGER-CAT	Hybrid	Worldwide	Landscan	Population+Buildings
PAGER-Analytical	-	Analytical	Worldwide	Landscan	Population+Buildings
ELER-Level 0	Badal and Samardzhieva	Empirical	European	Landscan	Population

ELER-Level 1	Coburn+Spence	Hybrid	European	Landscan	Population+Buildings
ELER-Level 2	-	Analytical	European	Landscan	Population+Buildings
QLARM	QUAKELOSS2	Hybrid	Worldwide	Point-based	Population+Buildings
EQLIPSE–Q	CATDAT	Empirical	Worldwide	Point-based and Grid	Population+Buildings
EQLIPSE–R	CATDAT	Hybrid	Worldwide	Point-based and Grid	Population+Buildings

In this paper, a case study of the earthquake and resulting tsunami in Japan is shown with the EQLIPSE-Q and -R being compared with nine open source worldwide rapid loss estimation models, as well as with the results of some commercial models.

Methodology

The following summarises the methodology involved in the production of EQLIPSE-Q (Qualitative/Quantitative) and –R (Reanalysis).

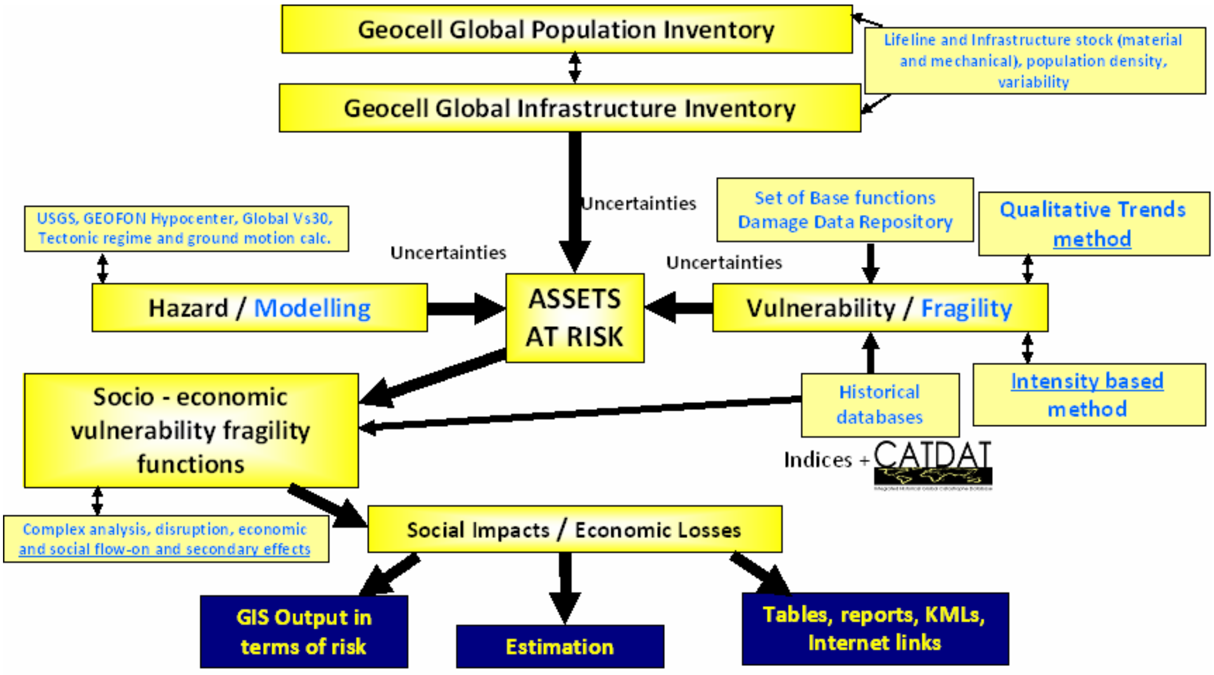


Figure 2: Components within CATDAT-EQLIPSE

As part of the production of a virtual earth through time, a global building inventory has been produced for examining building typologies in each country globally using census, technical report, WHE-PAGER, architectural reports, and journal papers for urban and rural building typologies, giving details as to wall, roof, age, storey heights, occupancy rates and building numbers. Over 1500 census rounds from over 200 countries have been audited.

The temporal-spatial indices produced have included the first country-based HDI value consistent from 1900 onwards, unskilled wage, GDP (PPP and nominal), CPI, construction cost, life costing and exchange rate data as well as point-based urban and rural population estimation. In addition, a combination of CIA Factbook, UN Census Round information and other population estimation sources (CIESIN, worldgazetteer and Urbaninfo) data supplements this work trended through the time using population trends for each discretised country worldwide. Assumptions as to how former republics operated have also been incorporated but allow for current country borders. Over 220 socio-economic indicators make up the spatial indices (current to 2011).

The development of new country-based social and economic indices provides an input to change the vulnerability functions into socio-economic vulnerability functions in order to better convert to economic and social losses, as well as allow for comparison between historic earthquakes. These have been produced in two ways 1) temporal-spatial – containing data from 1900 or before until 2011 for each country, and 2) current socio-economic indices. The vulnerability functions have been calibrated using both types of indices.

For EQLIPSE-Q, calibrated socio-economic fragility functions are formed following the development of a global historic damaging earthquake database, CATDAT, which has been undertaken over many years. The population and its social and economic status for each earthquake have been compared to the detailed socio-economic data in CATDAT to produce these functions. These discretised functions have been consistent with the changing vulnerability and exposure through time and allow for improved socio-economic conversion from building damage and other causes.

For the EQLIPSE-R model in addition to CATDAT data, existing empirical and analytical functions from various authors have been modified via building practice, corruption indices and seismic code data to develop the vulnerability functions. This is then calibrated by information on the ground.

Table 2: Loss Estimation Details within CATDAT EQLIPSE-Q and R

Parameter	CATDAT EQLIPSE-Q	CATDAT EQLIPSE-R
Hazard	Intensity Map, Point and finite-source and Magnitude/Depth	Intensity Maps (Local and USGS), Point and finite-source and Magnitude/Depth
Site Amplification	PAGER $V_{s,30}$ & Site Amplification Factors	PAGER $V_{s,30}$ & Site Amplification Factors
Inventory	EQLIPSE Hybrid Population, Global Building Inventory, Use.	EQLIPSE Hybrid Population, Global Building Inventory, Use.
Vulnerability Method	Normalisation Strategies	Hybrid Vulnerability Functions
Building Damage	EMS98 Intensity, MDF, Uncertainties	EMS98 Intensity, MDF, Uncertainties
Casualty Method	Regional EMS98, Population vs. Fatality Relationships adapted historically	Building damage casualty functions based on historical CATDAT data
Economic Method	Sectoral Analysis and Historical Losses adapted using HNDECI and Normalisation Strategies	Sectoral Analysis directly calculated from building and economic parameters
Sectoral and Socio-economic Data	CATDAT Social and Economic Database	CATDAT Social and Economic Database

Tohoku Earthquake 2011 Case Study

A focus on casualty and total economic loss estimation for the Tohoku earthquake of 11 March 2011 will be shown in this paper. The problem started that, given a Mw9.0, no existing intensity prediction equations or GMPEs were valid. Thus, it was decided that the JMA instrumental intensity based on PGV would be used as a proxy for the loss estimate. This was available via the JMA website in broad format. A model was then used to fit this as best possible given the source information. In this case various IPEs in Japan, such as Bakun (2004), were used. However, it was found that the Honshu model of Bakun (2004), rather than the offshore model, actually fitted better to the JMA instrumental intensity for a M9 event.

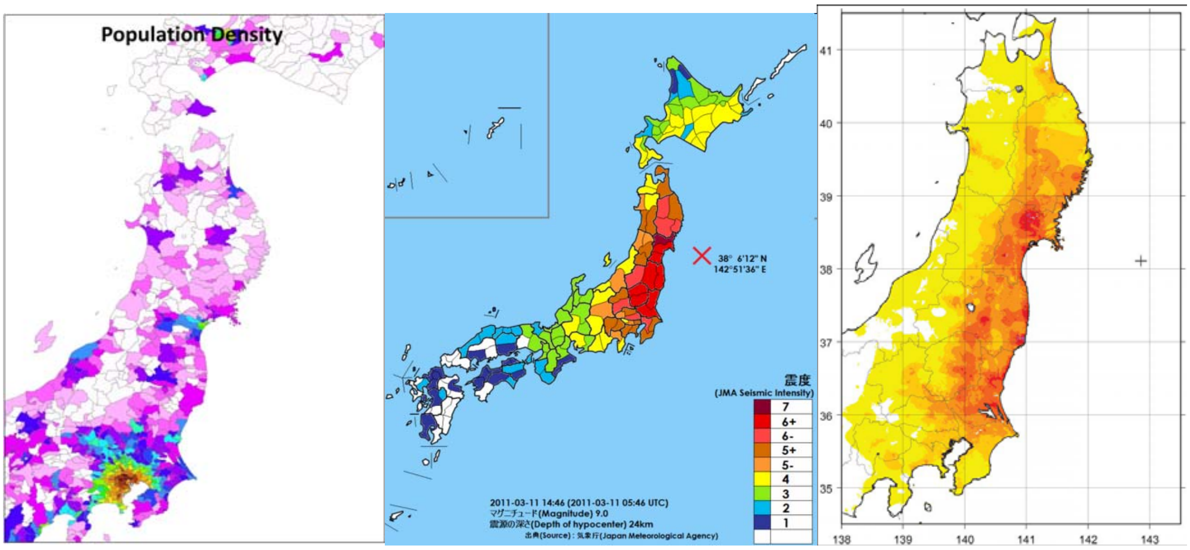


Figure 3: Population Density in Japan (left); JMA Intensities as determined via PGV at stations (JMA, 2011) (centre and right)

The existing models in terms of population and buildings affected by shaking were then checked with comparisons of the exposure of GDACS and PAGER. It can be seen that the EQ-R JMA average version has a lower average number of people within each of the intensity bins compared to the latest PAGER version. The most significant change can be seen between the loss estimates of the M7.9 versions (V1).

Table 3: Population Estimation Details within the various versions of software (k=1000 people)

	PAGER					EQ-Q	EQ-Q	EQ-R	EQ-R	EQ-R	GDACS
MMI	**V1**	**V3**	**V5**	**V6**	**V12**	**V1**	**V2**	**JMAlo**	**JMAup**	**JMA**	
IV	**3227k***	**--***		**560k***	**21353k***	**34464k**	**19232k**	**--**	**--**	**--**	
V	**6192k**	**--***	**7071k***	**18381k***	**8612k***	**6467k**	**5734k**	**12080k**	**6630k***	**8876k***	**R=200km**
VI	**2918k**	**2472k***	**19695k***	**18482k***	**10080k***	**4147k**	**3117k**	**21095k**	**18627k**	**26225k**	**4893k**
VII	**719k**	**7986k***	**29969k***	**28603k***	**34125k***	**3447k**	**2675k**	**7065k**	**16590k**	**7820k**	**R=100km**
VIII	**0**	**2598k**	**2144k**	**5529k***	**6009k***	**1839k**	**1872k**	**2700k**	**5439k**	**3756k**	**318k**
IX	**0**	**0**	**0**	**2k**	**251k***	**168k**	**630k**	**23k**	**563k**	**97k**	
X+	**0**	**0**	**0**	**0**	**0**	**0**	**30k**	**0k**	**10k**	**0k**	

*conversion of JMA to MMI via 1.95*Ijma-2.91 **JMAup was not used as the upper bound

The building inventory has been collected as part of the EQLIPSE building inventory from various census data and other sources as per the following references (Daniell et al., 2011b, Daniell, 2010b, Daniell, 2010c). In addition, the sectoral and socio-economic data indicates the industry and other exposure elements.

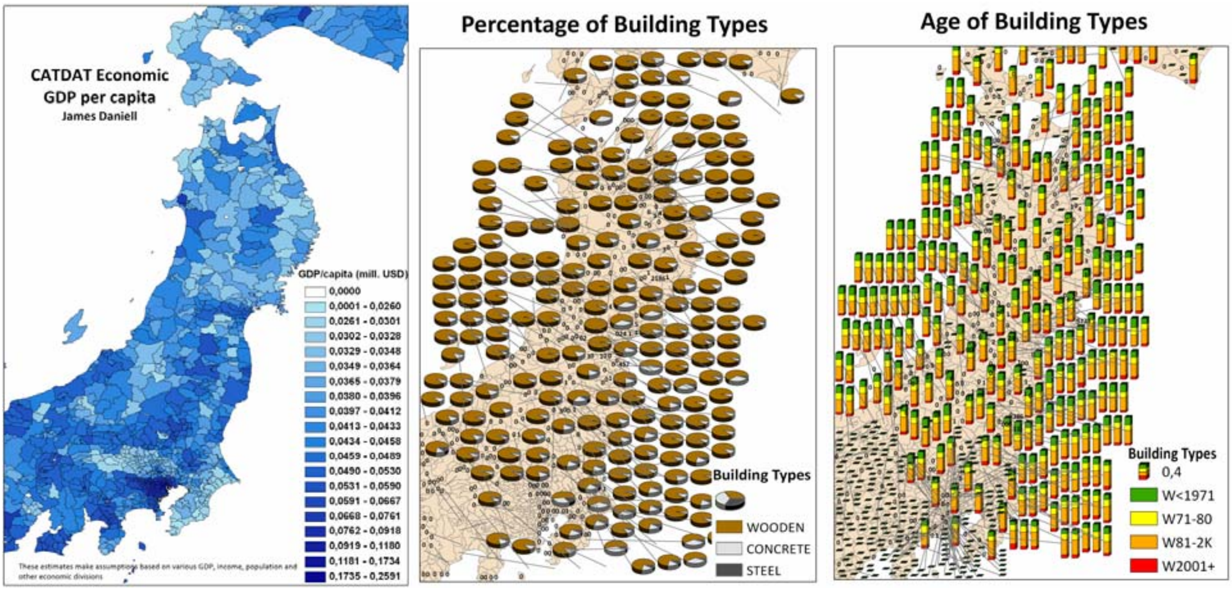
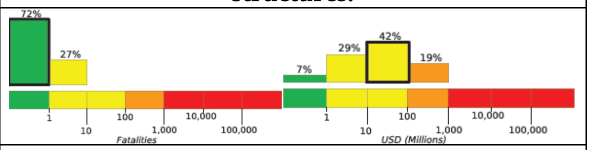
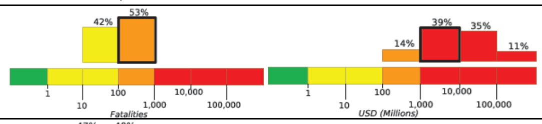
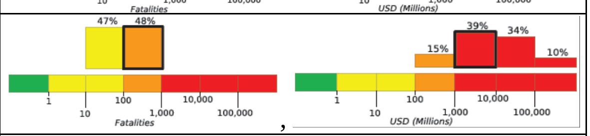
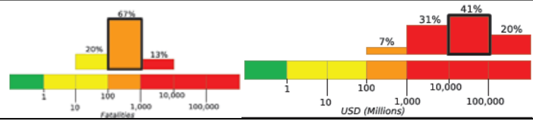
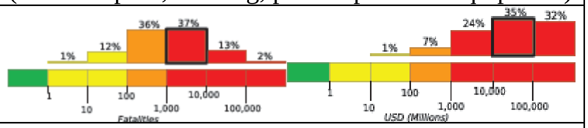


Figure 4: CATDAT GDP per capita (left); Age of building types (centre); Percentage of building typologies (right).

The following is a comparison of estimates of casualties and economic losses from various estimation models. All results represent only shaking losses from PAGER and QLARM. Economic Losses and casualties from EQLIPSE-Q and R are as indicated.

Table 4: Socio-economic loss estimates from various sources for the 2011 Tohoku EQ.

Software	Time since event	Magnitude	Estimate NB: PAGER = Shaking losses only to structures.
USGS PAGER v1	22min 58sec	Mw7.9	
CATDAT EQLIPSE-Q v1	24min	Mw7.9	\$5b-50b (Shaking only) but tsunami expected
WAPMERR QLARM	similar	Mw8.5	0-1000 fatalities, 0-200 injuries
CATDAT EQLIPSE-Q v2	70min	Mw8.8, Tsu.	925 (291-1340) shaking related deaths + 10000-20000 tsunami deaths (using a 90-95% assumption) \$125 billion to \$480 billion USD (70% tsunami) - \$259 billion median total loss
USGS PAGER v3	75min	Mw8.9	
USGS PAGER v5	2hrs44min-2hrs47min	Mw8.9	
Credit Suisse	1 day	Mw9.0	\$10 billion to \$50 billion
Some Analysts	1.5-2 days	Mw9.0	\$122 billion
CATDAT EQLIPSE-R v1	2 days	Mw9.0	\$159 billion direct losses, \$144 billion indirect (5-yr) 520 shaking deaths
Credit Suisse	2.5 days	Mw9.0	\$171 billion to \$183 billion
EQECAT	3 days	Mw9.0	>\$100 billion USD (\$20b homes, \$40b infrastructure) Insured Losses: \$15b-25b (16/03), \$22b-\$39b (09/05)
RMS	3 days	Mw9.0	\$200 billion - \$300 billion
Citigroup	3 days	Mw9.0	\$61 billion - \$123 billion (5 to 10 trillion JPY)
JP Morgan Chase	3 days	Mw9.0	>\$123 billion

USGS PAGER v6	3 days, 16hrs	Mw9.0	
Goldman Sachs	5 days	Mw9.0	$197 billion (16 trillion yen)
Barclays Capital (Morita and Nagai, 2011)	5 days	Mw9.0	$183.7 billion (15 trillion yen)
World Bank	6 days	Mw9.0	$122 billion to $235 billion. (Government of Japan and private estimates)
CATDAT EQLIPSE-R v2	7 days	Mw9.0	$257 billion direct.
IHS Global Insight	8 days	Mw9.0	$250 billion direct (20 trillion yen)
Economics Minister Kaoru Yosano	9 days	Mw9.0	$248 billion (>20 trillion yen)
Japanese Government (Kyodo)	13 days	Mw9.0	$197 billion - $308 billion direct losses. (Social capital, housing, private plants & equipment)
USGS PAGER v12	15 days	Mw9.0	
CATDAT EQLIPSE-R v3	20 days	Mw9.0	$249 billion direct, $55 billion indirect (current) with range of $249b-$512b
KISER Report	32 days	Mw9.0	Direct: 17.78 trillion JPY ($212b) (5.2 trillion JPY Housing, 7.24 trillion JPY Infrastructure, 3.62 trillion JPY Private Sector, 1.28 trillion JPY Ships, Cars, Transport, 0.44 trillion JPY Inventory/Other)
CATDAT EQLIPSE-R v4* (only EQ & TSU)	42 days	Mw9.0	Direct: $281b ($195b-$320b), Indirect: $70-175b (2-yr), $147-286b (5-yr)
Japanese Cabinet Office	3 months	Mw9.0	Direct: 16.4 trillion JPY ($208 billion) for the 4 largest prefectures (8.4 trillion JPY Infrastructure, 2.4 trillion JPY Homes, 1.6 trillion JPY Manufacturing, 4.0 trillion JPY Other)
Miyagi Prefecture	7 months	Mw9.0	Direct Losses: 7.2093 trillion JPY as compared to Cabinet office estimate of 6.492 trillion JPY.

*Does not include powerpoint losses beyond a $20b direct loss for the Fukushima plant destruction and decommissioning.; Other estimates of the reconstruction and cleanup from the Japan Center for Economic Research is at least 5.7 trillion JPY (USD 71bn); and from media sources by USD 250 billion (media estimates, SPARISK (2011)). The estimate directly from TEPCO is 4.5 trillion JPY (USD58.6 billion).

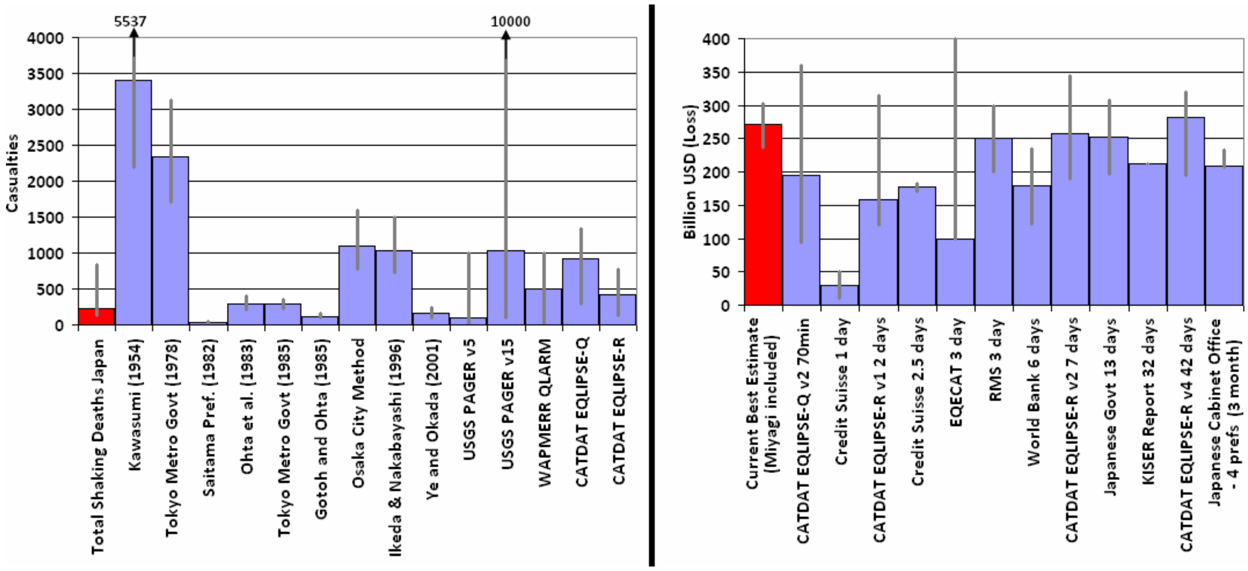


Figure 5: Various Casualty Models from Table 5 (Left); Various Economic Loss Estimates from Table 4.

Casualties

There were 46954 shaking deaths in Japan in the CATDAT Damaging Earthquakes Database from 1900-2010 before the 2011 Tohoku Earthquake. Of these, most occurred in the 1923 Great Kanto EQ (28560 shaking deaths), 1927 Tango EQ (3110), 1943 Tottori EQ (1325), 1945 Mikawa EQ (2306), 1948 Fukui EQ (4618) and 1995 Kobe EQ (4823). Thus, modelling these as well as all fatal and non-fatal earthquakes has given the casualty model base in the same methodology as per PAGER. In addition, the use of the seismic code index, other social vulnerability and building practice indicators and other normalisation strategies ensures that the casualty model is calibrated to today's conditions. It would be inaccurate to simply use casualties from a 1970 earthquake, as 80% of the Japanese building stock has been built since.

A comparison of results from various empirical Japanese casualty estimation models is shown for the M9 earthquake using a basis of 13000-26000 destroyed buildings and 74000-126000 half-destroyed buildings as a result of the earthquake. This is in comparison to the 92000 buildings destroyed and 78000 houses partially destroyed by the tsunami. MMI>7-7.5 townships were used for the regression methods of Ye and Okada (2001) and other methods.

Table 5: Casualty range loss estimates from selected casualty models for the 2011 Tohoku EQ for earthquake shaking deaths.

Casualty Model	Lower	Median*	Upper
Kawasumi (1954)	2187	3410	5567
Tokyo Metropolitan Government (1978)	1716	2334	3132
Saitama Prefecture (1982)	35	39	43
Ohta et al. (1983)	210	288	409
Tokyo Metropolitan Government (1985)	229	291	360
Gotoh and Ohta (1985)	95	120	156
Osaka City Method	781	1098	1601
Ikeda and Nakabayashi (1996)	729	1026	1496
Ye and Okada (2001)	104	163	244
USGS PAGER v12	100	1030	10000
WAPMERR QLARM	0	Unk.	1000
CATDAT EQLIPSE-Q	291	925	1340
CATDAT EQLIPSE-R	133	420	781
Total Shaking Deaths from Japan	**150**	**230**	**350**

*median estimate equals 18207 destroyed houses, 100414 partially destroyed.

It is unknown how many victims have died directly due to the earthquake action. As reported on earthquake-report.com in April 2011 from NPA, among the first 13135 victims, 92.5% were drowned (12143), 4.4% were crushed to death mainly in tsunami collapsed houses (578), 1.1% were burned to death in various fires (148), with others killed via hypothermia and other causes. It will never be known how many died due to the earthquake, as separated from the tsunami; however, the autopsies give us an indicator that we can expect that about 1.0% of the 4.4% crushed were probably in earthquake collapsed houses.

In addition, we can assume a proportion of the remaining 2% that were unknown were also earthquake-related (a high value of 10% could be assumed). This would leave about 1.2% or about 158. When extrapolating for the final 6000 deaths that were not stress or chronic disease related, then the total is around 230. This value corresponds quite well to the 137 non-tsunami impacted deaths that have been recorded in the non-coastal areas. Some of the non-coastal deaths, however, were due to heart attack, fire or landslide.

As of 30 September 2011, 15815 have been killed and 3966 are missing (19781 in total). Of the 19781, around 600 are assumed to have died from earthquake-related stress and chronic disease. Around 230 should be earthquake-collapse related. Around 250 could be related to other causes such as fire, landslides etc. Around 94% of deaths are tsunami related.

This means that the most reasonable estimates have been derived from Ohta (1996). PAGER, QLARM and EQLIPSE all performed reasonably well, given the uncertainty of the number of shaking deaths, 5 months after the event. PAGER version 6 seems the most accurate of the estimates, whereas EQLIPSE-R, as expected, performed better than EQLIPSE-Q.

Direct Losses

The initial direct losses in CATDAT EQLIPSE-Q are built via normalisation of various parameters of historic earthquakes to 2011 conditions using population and dwelling changes, vulnerability changes, and community wealth changes as per Daniell and Love (2010). In addition, this uses the HNDECI index for each historic earthquake. Sectoral analysis from past Japanese earthquakes gave a predicted ratio for the initial loss.

The estimates from CATDAT were distributed on earthquake-report.com with the release of a $100 billion to $500 billion estimate (total, with 70% coming from tsunami), created after 70 minutes (Daniell et al., 2011a, Daniell et al., 2011c). The uncertainties come about because of the great uncertainties in modelling losses given certain intensities and the uncertainties in damage ratios and industries affected. Historically in such events, 20-30% of direct economic loss was residential based, with ranging estimates from 25-55% in other forms of industry, infrastructure and commercial losses. These relationships are based on historic large Japanese earthquakes, some of which are shown in Figure 5. In EQLIPSE-R, the income level and historic losses to residential buildings were calculated based on potential losses in each municipality, as seen in the example

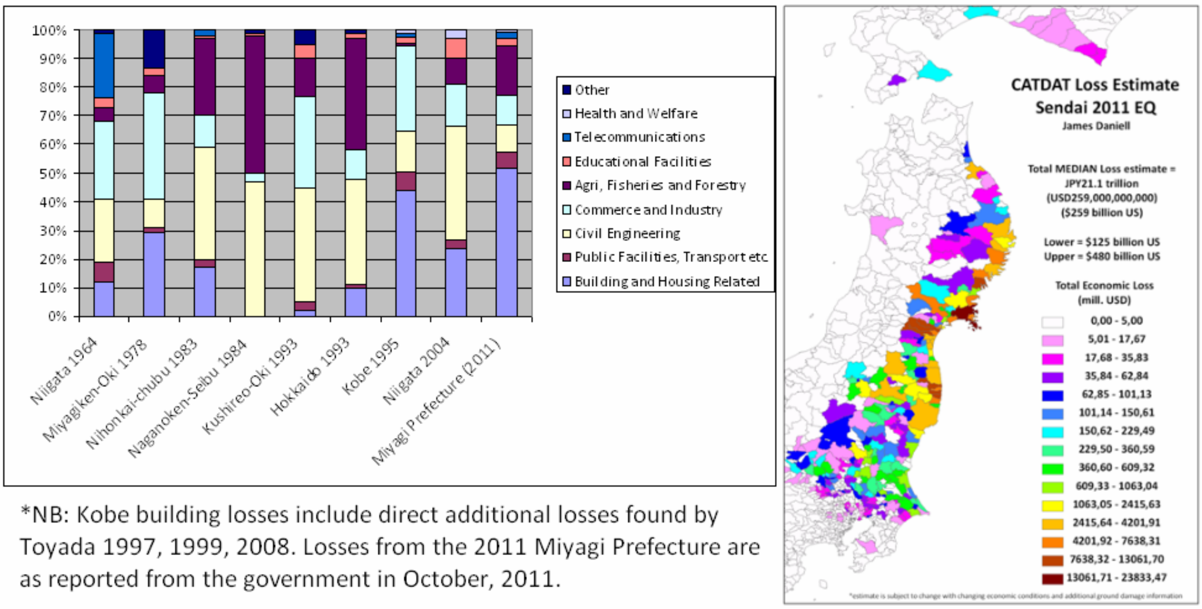


Figure 6: CATDAT EQLIPSE-Q v2 economic loss (left); Sectoral loss distribution from historic Japanese earthquakes in terms of direct economic losses (right).

Around 70% of the capital stock is inland as compared to around 30% of the capital stock on the coast in the provinces of Miyagi, Iwate, Fukushima and Ibaraki according to the Japanese Cabinet Office. Extrapolating the damage in other prefectures, the Japanese Cabinet Office estimate should be about $231 billion once adding $23 billion loss in other prefectures. In addition the estimate of the Miyagi Prefecture of incurred direct losses (incomplete as of

17/10/2011) is 11% greater than the original Cabinet estimate. With currency changes and this increase, the direct loss estimate at this point from the Japanese government appears to be $271 billion (without the additional $58-71 billion expected from Fukushima). Using the intensity relationships created in the buildings from non-coastal municipalities (as nearly all damage in these municipalities inland must be earthquake related), then the following distribution results in tsunami and earthquake losses from Daniell et al. (2011).

Table 6: Building damage statistics for the 2011 Tohoku EQ disaggregated for tsunami and earthquake.

Buildings	Destroyed	Partially Destroyed	Partially Damaged
Tsunami	92168-104967	51322-103986	23892-72885
Earthquake	12813-26285	74253-127408	539595-590416

An additional 35466 buildings are in the towns and cities within the exclusion zone of the Fukushima I and II nuclear sites. The best estimate of damage to buildings from Daniell et al. (2011) coming from each of the three events is the earthquake (49%), tsunami (39%) and nuclear disaster (12%). With total direct losses, this reduces to earthquake (44%), tsunami (38%), nuclear disaster (18%).

Indirect and Sectoral Losses

The power shortage was assumed at the time to contribute to ripple effects of up to 1 trillion JPY or about $12 billion USD. This was calculated by Kouno (2011) to be a direct loss of 166.3 billion JPY, with all inter-industry effects adding up to 1.5 trillion JPY. The differences in losses differ from the view seen in Kobe 1995 due to the differences in economic makeup, density and area impacted. From historical quakes and looking at business interruption, for a $280 billion direct economic loss from this earthquake, around $110 billion (2-yr) to $220 billion (5-yr) in extra indirect losses could be expected for the earthquake and tsunami. Further analysis will be needed over the coming years.

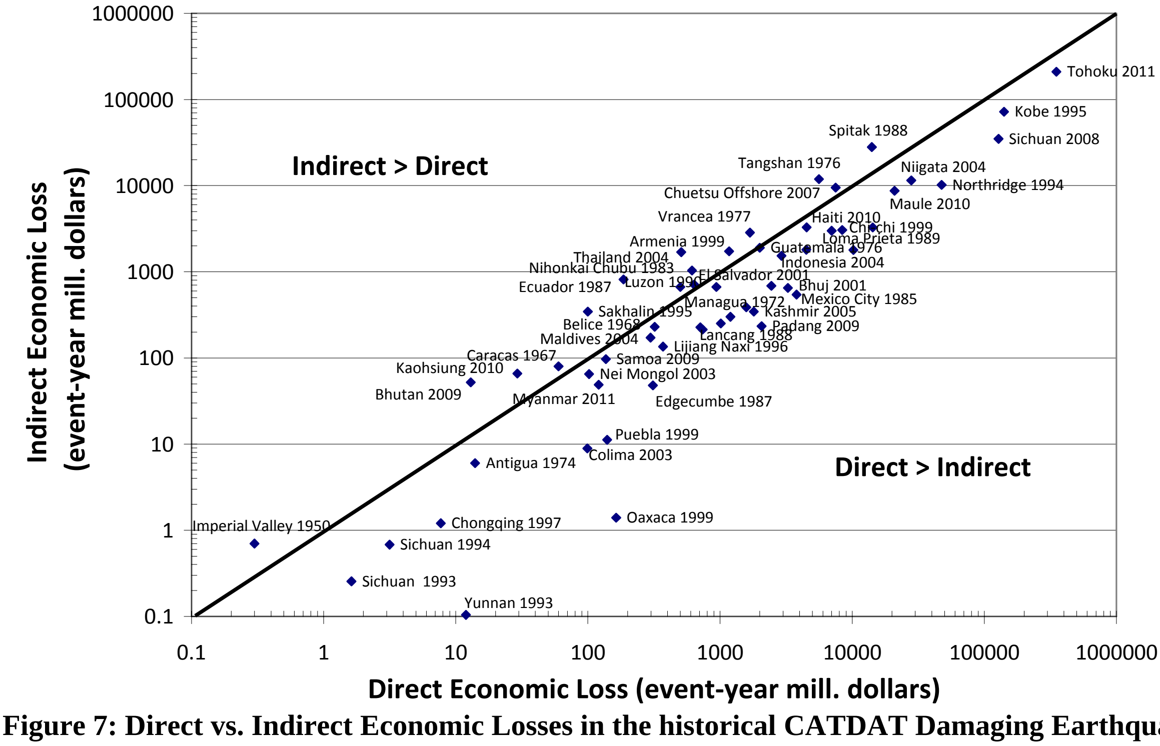


Figure 7: Direct vs. Indirect Economic Losses in the historical CATDAT Damaging Earthquakes Database.

These are simply modelled using GDP sector influence within each of the affected locations and then using past earthquakes in Japan and other locations as a basis to see the influence of loss on top of the expected direct losses. Shown below is the ratio of Indirect to Direct Losses in various earthquakes from the CATDAT Damaging Earthquakes Database.

Conclusion

The Tohoku earthquake in 2011 has provided a situation where the size of the event was outside the expected values. Historical GMPEs and IPEs used for historic Japanese earthquakes were outside of the magnitude range (Mw=9.0). This made difficulties for the modelling of intensities and damage.

A number of rapid earthquake loss estimation software packages exist worldwide (PAGER, QLARM, EXTREMUM) and have been shown to create reasonable estimates of loss in quick time after a disaster. CATDAT EQLIPSE aims to integrate a higher level of socio-economic analysis and historic earthquake data into rapid loss calculations through a dynamic nature. In the case of the 2011 Tohoku earthquake and tsunami, it is difficult to know the final discretisation of earthquake and tsunami losses; however, the possible outcome is about 39% economic losses due to tsunami ($127 billion) and 43% due to the earthquake ($144 billion), with about 18% due to the Fukushima disaster ($59 billion). The data from Miyagi prefecture has shown these percentages to be realistic. On the other hand, approximately 94.5% of the deaths are expected to be tsunami related, with only a small percentage (1.2%) expected due to earthquake shaking. Direct Losses are in the order of $335 billion with indirect losses around $260 billion expected with all impacts combined.

Table 7: Final loss estimates for the 2011 Tohoku EQ disaggregated for tsunami, powerplant and earthquake using Japanese and CATDAT data as of 18th October.

<table>
<tr><th>In Billion USD</th><th>Earthquake</th><th>Tsunami</th><th>Powerplant</th></tr>
<tr><td>Direct Loss Inland</td><td>77</td><td>0</td><td rowspan="2">58-71</td></tr>
<tr><td>Direct Loss Coastal</td><td>48-81</td><td>112-145</td></tr>
<tr><td>Total Direct Loss</td><td>125-158 (42%)</td><td>112-145 (39%)</td><td>58-71 (19%)</td></tr>
<tr><td>Indirect Loss</td><td>69-132</td><td>64-113</td><td>51-91</td></tr>
<tr><td>Total Economic Loss</td><td>194-290 (41%)</td><td>176-258 (36%)</td><td>109-162 (23%)</td></tr>
</table>

EQLIPSE-Q and R are in production currently and much work is still required for automation of the process. Further details of the socio-economic functions included in EQLIPSE will be calibrated and then disseminated in future papers (Daniell, 2011b).

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