EEFIT

The Institution of Structural Engineers

GEM GLOBAL EARTHQUAKE MODEL

The EEFIT Mission to Japan after the M_W9.0 Tōhoku Earthquake: Key Findings and Lessons Learned

By A. Pomonis (Team Leader)
Director, Cambridge Architectural Research, Ltd.
on behalf of the EEFIT Mission to Japan Team Members

Seminar on Disaster Research in the UK and Collaboration with Japan,
British Embassy in Japan, Tokyo
October 5, 2012

Earthquake Engineering Field Investigation Team

EEFIT's 31 YEARS' HISTORY (1982-2012)

- **The Earthquake Engineering Field Investigation Team (EEFIT), is a joint venture between industry and universities operating under the auspices of the UK's Institution of Structural Engineers.**
- **Its nearly 100 members are earthquake engineers and academics who collaborate with colleagues around the World to improve the seismic resilience of traditional and engineered structures.**
- **EEFIT's principle activity is to conduct field investigations following major earthquakes and to publish findings via the issue of free-for-all comprehensive reconnaissance reports and web-cast seminars (http://www.istructe.org/resources-centre/technical-topic-areas/eefit/eefit-reports).**
- **EEFIT has so far launched 33 missions with the mission to Tohoku being its latest.**

2010 Haiti Earthquake

2010 Chile Earthquake

THE EEFIT MISSION TO JAPAN IN 2011

- **Mission members and leader are vetted from submitted applications**
- **Usually a mixture of senior and junior academics & engineers is selected**
- **9 team members from the UK incl. two UK-based Japanese academics;**
- **3 Japanese academics accompanied the team and collaborated in the preparation of the report and on follow-up research projects;**
- **20 Japanese academics and professionals assisted during the preparation, execution and follow-on activities of the mission**
- **The mission took place May 29 – June 3, 2011 and focused primarily in Miyagi & Iwate prefectures**

MAIN MISSION OBJECTIVES

- **Investigate damage to buildings due to ground shaking;**
- **Carry out damage surveys nearby strong motion recording stations;**
- **Investigate landslide, coastal subsidence and liquefaction effects;**
- **Investigate performance of industrial facilities (ground shaking & tsunami);**
- **Investigate the effectiveness of coastal defences in the affected regions;**
- **Collect data on run-up heights and inundation distance inland;**
- **Understand the efficiency of tsunami warnings and evacuation;**
- **Assess effectiveness of vertical evacuation structures during the tsunami;**
- **Establish contacts & exchange information with Japanese organisations involved in response & recovery and Japanese academic community.**
- **Investigate the use of new technologies in disaster management & prevention**

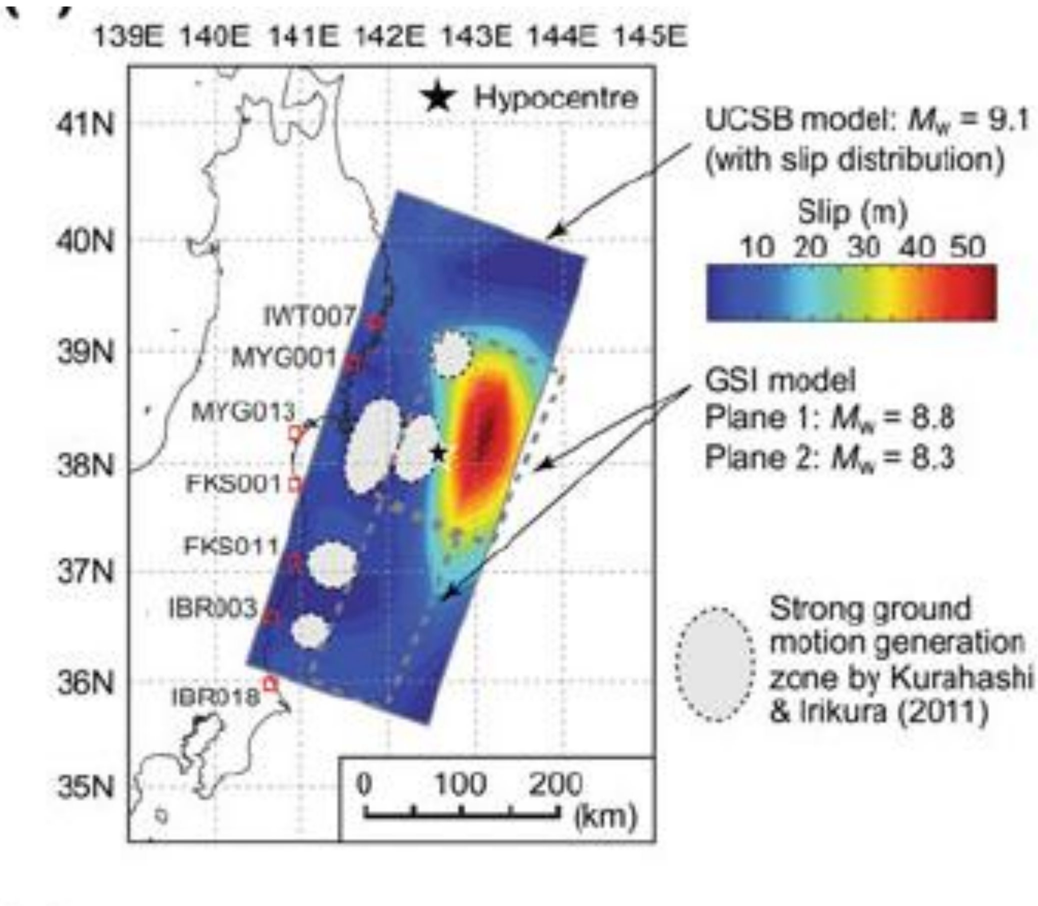
THE EEFIT REPORT ON THE 2011 EARTHQUAKE

CHAPTERS ON:

- Geophysics
- Ground Motion & Shaking Damage
- Geotechnical Field Observations
- Energy Production Sector & Other Industries
- Coastal Structures, Tsunami Defences
- effects of the tsunami on buildings
- Human casualties, tsunami preparedness & evacuation strategies
- Review of Economic Losses
- Relief & Recovery
- Use of geospatial tools in disaster management
- 189 pages

AN UNPRECEDENTED MEGA-THRUST EARTHQUAKE IN THE JAPAN TRENCH

SOURCE: Goda, Pomonis et al., Bulletin of Earthquake Engineering, 2012



Previous great tsunamigenic earthquakes in Eastern Japan were the:

- **869 Jōgan earthquake;**
- **1611 Keicho Sanriku earthquake.**
- **But it is thought that none of these exceeded moment-magnitude 8.7**
- **The 2011 event ruptured 500x200 km of lithosphere, dipping towards the Sanriku and Tohoku coast**
- **Crustal strain measured by GPS had shown from 2003 (Igarashi et al.) that the area ruptured in 2011 had significant slip rate deficit, but it was thought unlikely that the entire zone would rupture in a single event (due to the old age of the lithosphere)**

HIGH VARIABILITY IN RECORDED GROUND MOTION

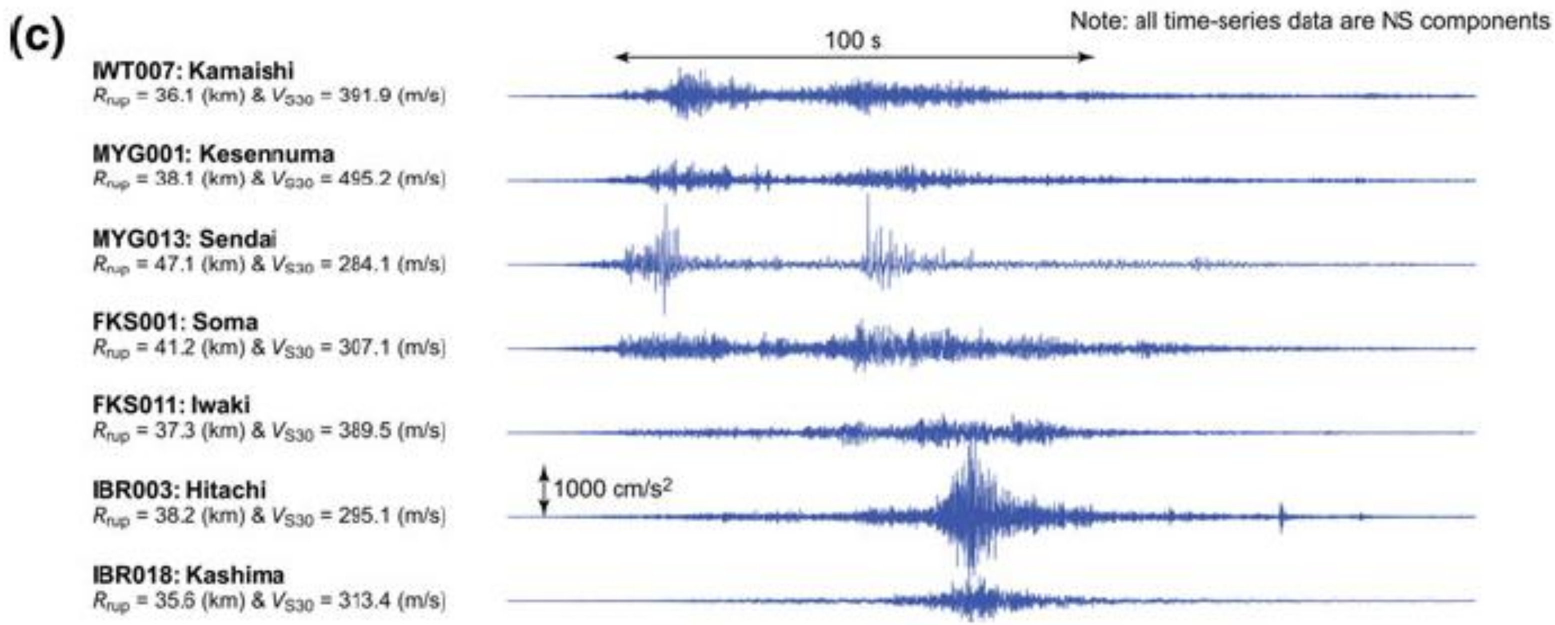


Fig. 1 a Fault rupture plane models of the 2011 Tōhoku mainshock, **b** spatial distribution of major aftershocks, and **c** observed ground motion (processed) time-series at seven K-NET stations

SOURCE: Goda, Pomonis et al., Bulletin of Earthquake Engineering, 2012

The rupture of several fault segments resulted in a mega-thrust earthquake with highly varied recorded ground motion across the Tohoku region with:

(i) Very high spectral content in short vibration period range,

(ii) Very long duration (~100 seconds),

(iii) Variability due to local asperities as well as direction of source rupture, in locations with similar site conditions and rupture distance.

GROUND MOTION DAMAGE POTENTIAL

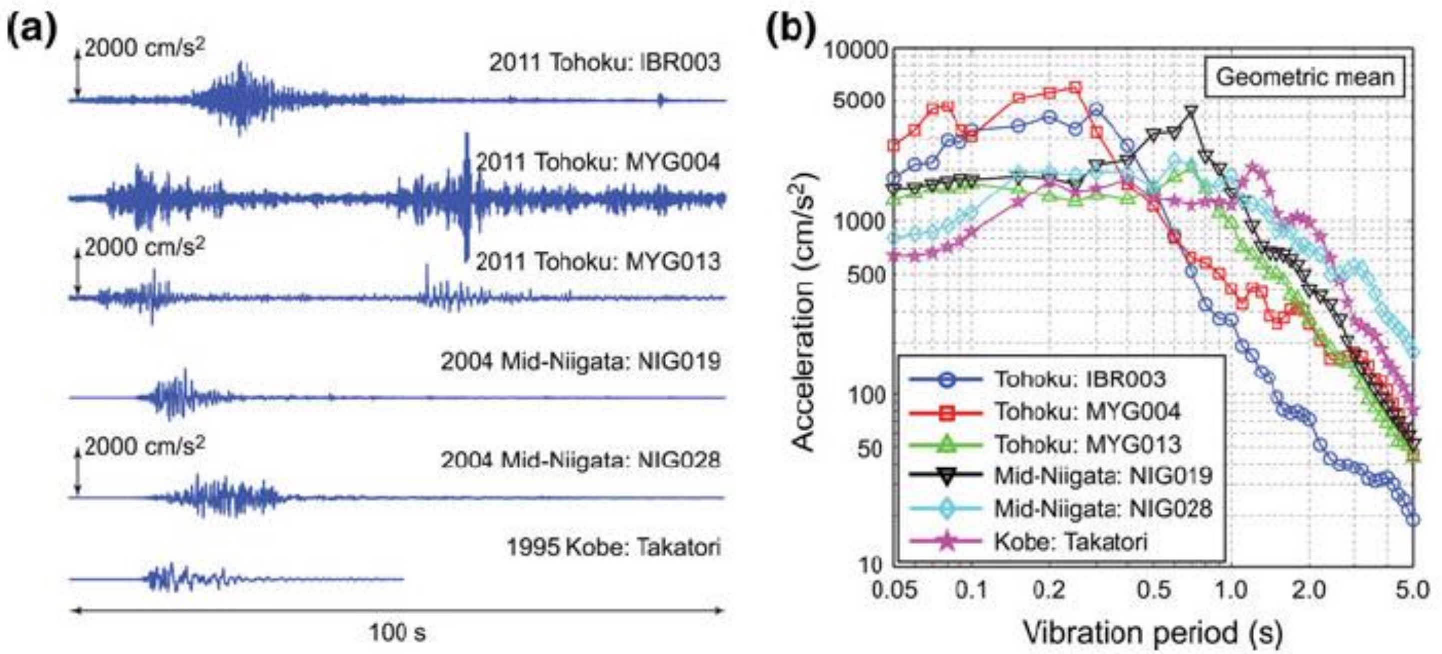
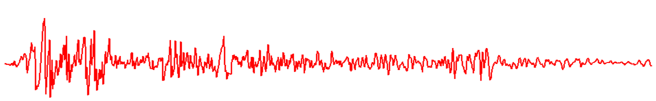


Fig. 6 Characteristics of three Tōhoku mainshock records and three significant records from the 2004 Mid-Niigata earthquake and the 1995 Kobe earthquake. **a** processed time-series data and **b** response spectra

SOURCE: Goda, Pomonis et al., Bulletin of Earthquake Engineering, 2012

Comparison with the recorded ground motions in 2004 Niigata-Chuetsu and 1995 Kobe earthquakes shows that the 2011 event produced motions with much greater energy content, higher peaks, higher spectral values in the lower period range (0.1-0.4s) and lower spectral values in the longer period range (0.5-1.5s).

Damage to wooden and non-wooden buildings was less severe than in Kobe.



GROUND SHAKING DAMAGE TO STRUCTURES

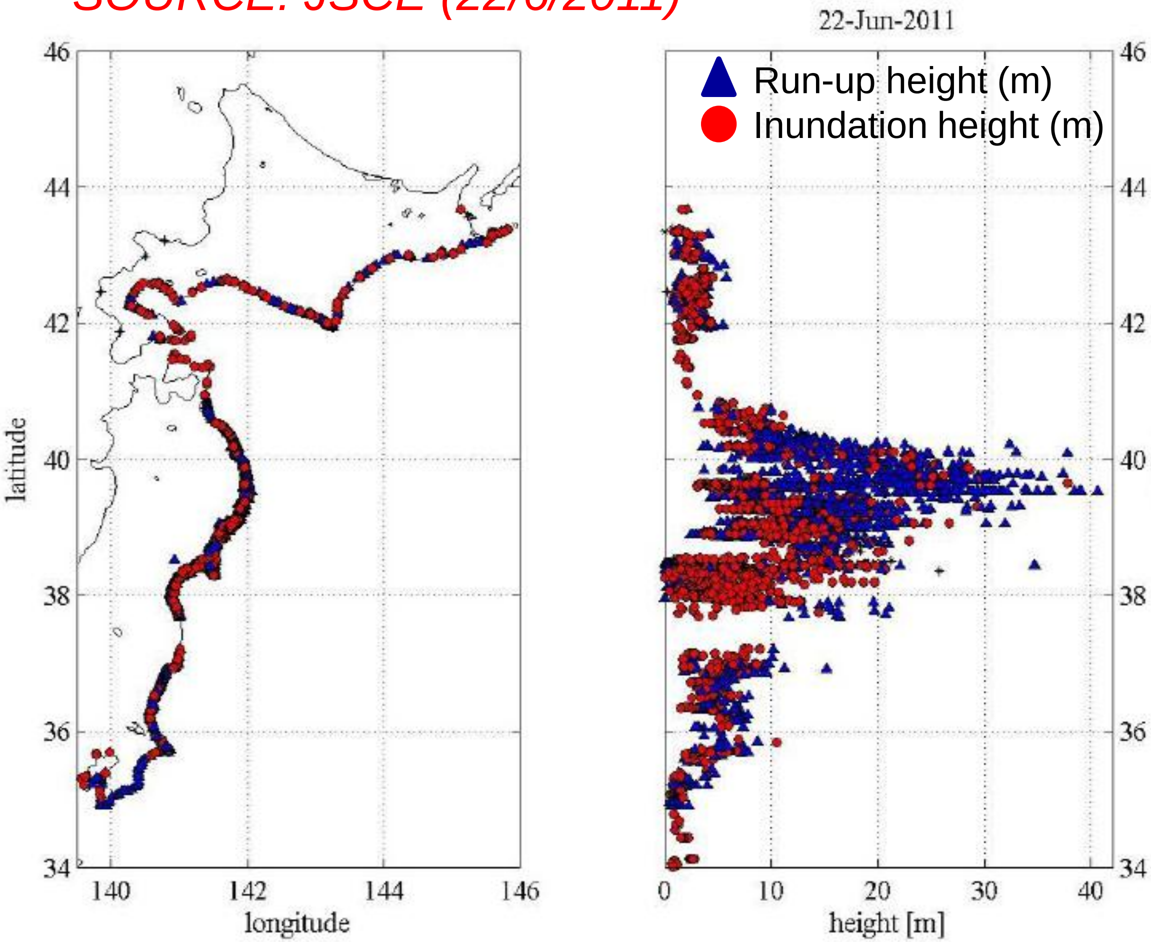
- **Post-1981 buildings performed better than older structures due to amendments to building codes.**
- **RC buildings: diagonal shear cracks and buckling of columns commonly observed in older buildings.**
- **Some high-rise buildings in Sendai will have to be demolished (one such structure was also damaged in 1978 Miyagi-oki earthq.)**
- **Old wooden structures highly susceptible to damage during strong shaking due to decay.**
- **Circa 100 deaths and 255 serious injuries occurred due to building collapse**

GROUND SHAKING: KEY FINDINS, LESSONS LEARNED

- **6.4 million people were exposed to shaking intensity VIII-IX (Mercalli scale)**
- **Only ~125 deaths and ~255 serious injuries occurred due to building collapse and geotechnical failures**
- **A high-rise building in Sendai damaged by the 1978 & 2011 earthquakes will have to be demolished**
- **Severe structural damage and collapse of pre-1981 RC buildings observed, but at much lower rates than in 1995 Kobe earthquake**
- **Vulnerability of old wooden dwellings re-affirmed**
- **~730,000 buildings suffered mostly light to moderate damage (most were old wooden dwellings)**
- **Performance of infrastructure (roads, bridges, railways) quite good although damage did occur to 4,200 roads, 116 bridges (few collapsed) and 29 railways. Recovery was very rapid!**
- **Ground motion characteristics thoroughly investigated, aided by Japan's excellent observation network and free access to the data via the internet**
- **Two detailed damage surveys carried-out in Sukagawa and Shirakawa, provided useful correlations between recorded motions and loss potential**
- **Ground motion of most significant aftershocks also investigated**
- **Several ground motion parameters' relation to damage potential understood and quantified**
- **Implications of ground motion due to mega-thrust earthquakes better understood**

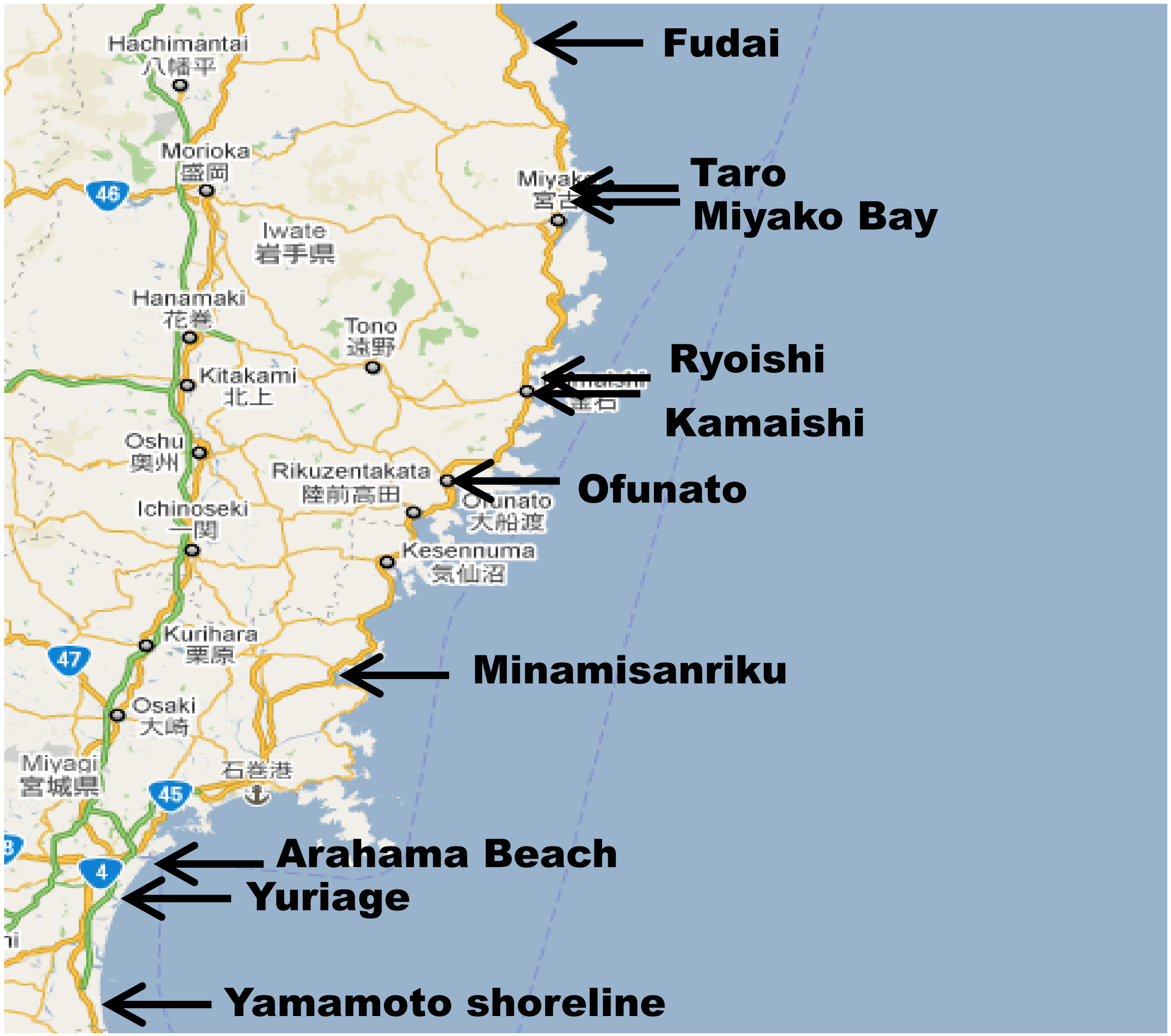
THE GREAT TSUNAMI IMPACT

SOURCE: JSCE (22/6/2011)



- More severe than 1896 & 1933
- 30 to 60 min lead-time
- 600 km of coast inundated
- 500 km^2 of land inundated
- 54 cities affected
- 602,000 people living in the inundated area
- 15,700 people drowned
- 2,800 people missing
- 129,500 buildings destroyed
- 301,500 buildings damaged
- Maximum run-up at ~41m
- Maximum inundation at ~38m
- Rapid attenuation N of 40.50 deg
- High tsunami mortality (>8%) in 7 cities
- Flat coastal areas south of Sanriku less well prepared
- Matsushima protected but Ishinomaki devastated
- Onagawa, Rikuzentakata, Otsuchi (>11% killed)
- Elderly mortality >20% in many of the affected cities
- 200 bn US$ economic loss & 30 bn US$ insured loss attributed to tsunami
- Nuclear disaster at the FDNPP, enormous long-term consequences

COASTAL STRUCTURES SURVEYED



PERFORMANCE OF COASTAL DEFENCES

Washout of Sand Infill

Catastrophic Failure of Revetment

Failed Seawall at Taro

- Sand infill washout and breaks in concrete lattice revetments.
- Enormous seawall failed at the “Town of Tsunami Disaster Prevention” of Tarō.
- Guinness Book of Record for deepest breakwater collapsed at Kamaishi.
- Success story at the town of Fudai; 15.5m high sluice gate suffered little damage and prevented overtopping of tsunami waves.

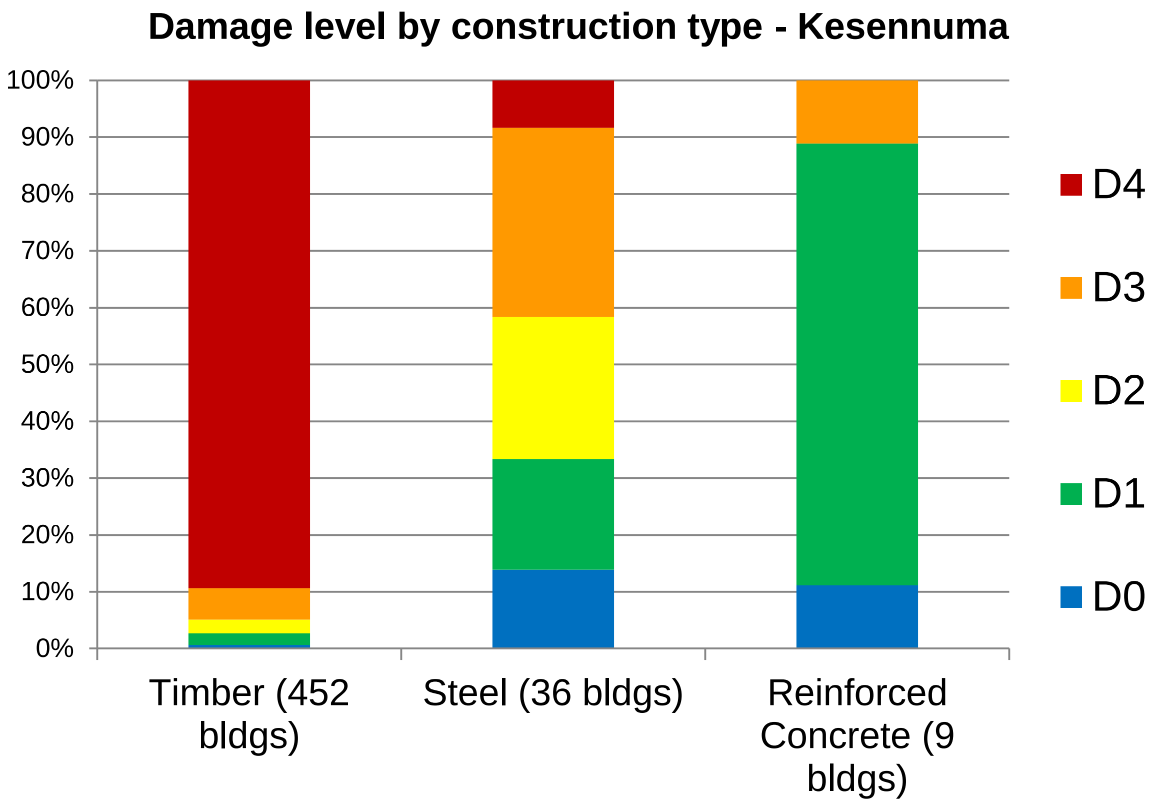
TSUNAMI DAMAGE TO BUILDINGS

- Tsunami height, velocity during inflow and backflow as well as debris impact are the principal factors in damage potential to buildings;
- Most wooden buildings were swept away when tsunami height >3 m;
- RC and steel frame buildings suffered extreme non-structural damage.
- In places of extreme tsunami height (>15 m) some RC and steel buildings of 2-4 storeys with small plan layout (some on pile foundations) were overturned and shifted up to 40m (e.g. Onagawa, Otsuchi, Miyako);
- Scouring due to fast-flowing tsunami around buildings reduced ground bearing support which led to tilting of buildings, e.g. Yuriage district (Natori).


Damage due to tsunami


Overturned building

TSUNAMI DAMAGE SURVEYS



- Two detailed surveys (Kesennuma & Kamaishi)
- Kesennuma (6m flow)
- Kamaishi (6 - 8m flow)
- EEFIT (2005) damage scale used for RC build.
- New damage scale proposed for Steel and Wood frame buildings
- Damage survey maps in the report
- Significant local variations in damage
- Effect of sheltering, velocity investigated

TSUNAMI HAZARD MAPS

Hazard map of, Minamisanriku

Yellow: Maximum inundation extent from the Chile earthquake in 1960.

Pink: Expected maximum inundation extent from the Miyagi off shore earthquake scenario.

Blue: maximum inundation extent resulting from the Tohoku Earthquake.

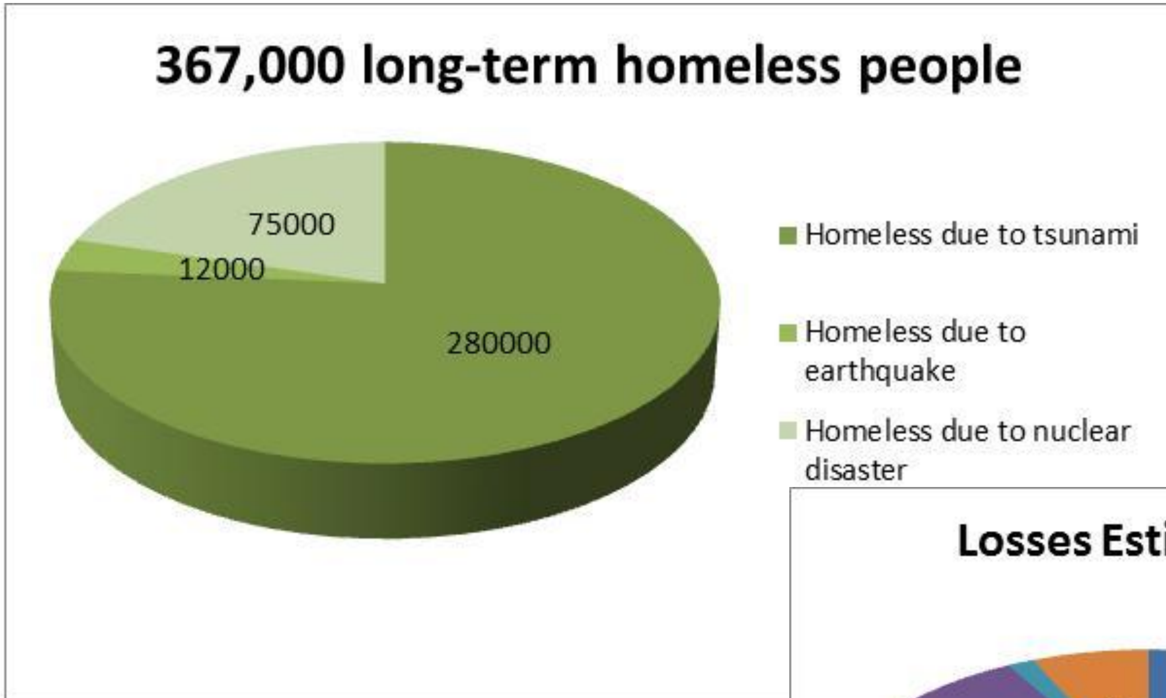
VERTICAL EVACUATION FACILITIES

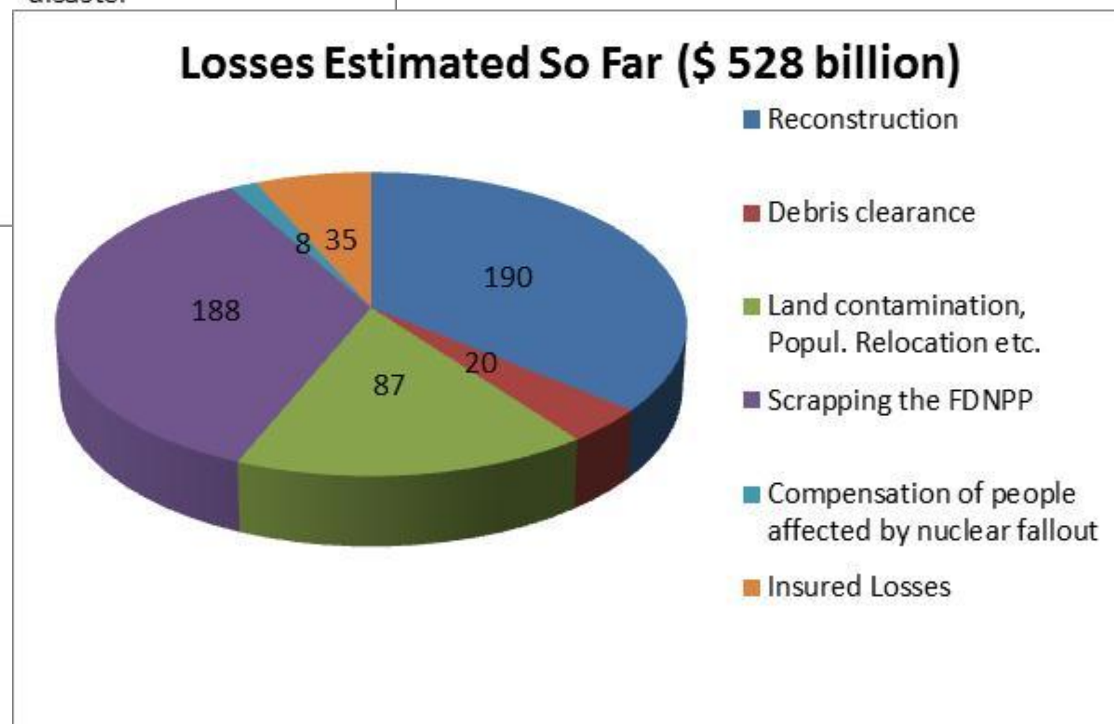
- **Most vertical evacuation structures performed well and helped reduce fatalities in tsunami affected towns and cities.**
- **Tsunami early warning and evacuation drills vital in ensuring effectiveness of the evacuation facilities.**

TSUNAMI: KEY FINDINS, LESSONS LEARNED

- **The 2011 tsunami is one of the most severe in human history as it affected 600 km of coast, 500 km^2 of land and 602,000 inhabitants**
- **Overall tsunami mortality reached 3%, which is quite low considering the severity of the event and the limited lead time for evacuation**
- **If a similar tsunami struck a region unprepared for tsunami evacuation (e.g. Aceh province in 2004) mortality would exceed 25% (>150,000 deaths)**
- **When examining the period 1946-2011 we see that in Japan 65% of 30,000 deaths are due to tsunami**
- **The extensive tsunami protection infrastructure was not able to provide the level of protection envisaged during its design, although it may have attenuated the consequences**
- **Vertical evacuation structures provided safe haven to tens of thousands of people but many were situated in harm's way**
- **Other designated tsunami evacuation places saved hundreds of thousands, although unfortunately some were overwhelmed by the tsunami**
- **In Japan special provision is needed for the evacuation of the elderly as those aged 70 or more formed >45% of the victims, but around 15% of the exposed population**
- **Wooden dwellings are extremely vulnerable and subject to floating when tsunami height is >3m**
- **No-wooden buildings suffer extreme damage to non-structural elements**
- **Better tsunami hazard maps needed, taking into account low-probability but high-consequence events. Evacuation planning to be accordingly developed.**

PRINCIPAL SOCIO-ECONOMIC CONSEQUENCES





DIRECTIONS FOR DISASTER RESILIENCE

- **Ground Shaking**
  - **Assessing need for retrofitting of buildings built before 1981.**
  - **Reduction of vulnerability of old wooden dwellings.**
- **Geotechnical**
  - **Re-evaluating geotechnical design against landslide, soil liquefaction and ground settlement.**
  - **Innovative solutions needed for protection of the areas affected by significant coastal subsidence.**
- **Tsunami**
  - **Improving prediction of tsunami heights from numerical modeling.**
  - **New hazard maps with better estimates of likely tsunami height and inundation extent.**
  - **Re-assessing design and provision of coastal defences, location of evacuation centres, minimum height and better situation of vertical evacuation structures.**
  - **Considering tsunami induced scour and overturning of buildings with shallow foundation.**
  - **Preparedness plans for debris removal and processing**
  - **Preparedness plans for recovery of flooded agricultural land**