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2011 Tsunami in Tohoku, Japan: Planning and Design of Vertical Evacuation Buildings

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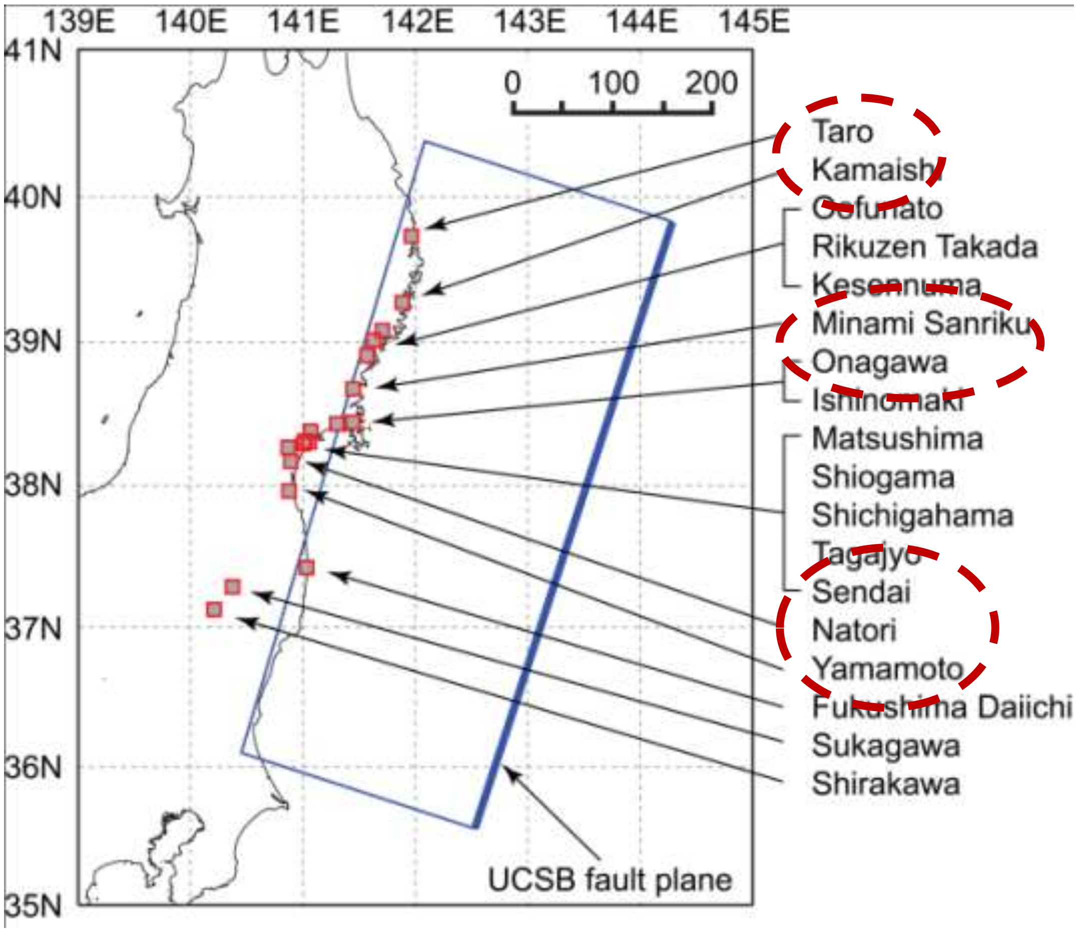
Content

- M_w9.0 11th March 2011 Tohoku earthquake and tsunami damage
- Performance of tsunami protection
- Vertical evacuation buildings – a case study for Yamamoto
- Key lessons to be learned

EEFIT-Tohoku Mission



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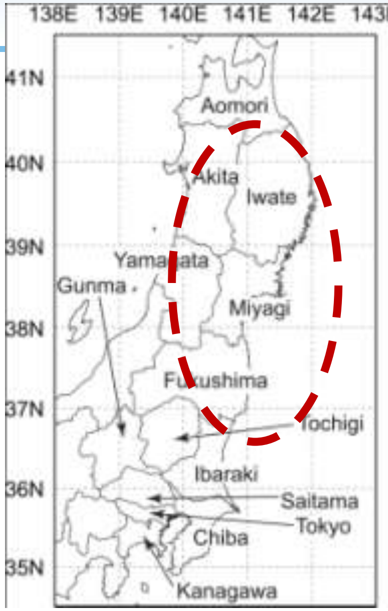
Earthquake Facts

- Very large earthquake: M_w9.0
- Catastrophic tsunami damage
- 19000+ death/missing
- Direct loss: 300-400 billion U.S. dollars
- Infrastructure damage – levee, road, bridge, railway, water treatment plant, industrial facilities, …
- Fukushima Daiichi nuclear power plant crisis

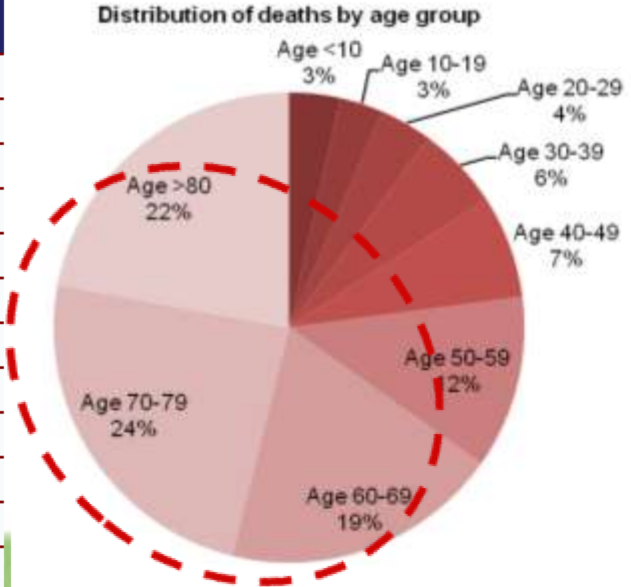
General Damage Statistics



- Widespread damage to buildings – concentrated in Iwate/Miyagi/Fukushima. This includes both tsunami-affected and shaking-affected cases.

Damage statistics from National Police Agency

Prefecture	Total collapse	Half collapse	Partial damage	Non-residential damage	Road
Iwate	**20998**	**3174**	**2668**	**1538**	**30**
Miyagi	**65462**	**48684**	**76785**	**17826**	**390**
Fukushima	**15885**	**29125**	**92455**	**1015**	**19**
Ibaraki	2179	14873	132921	8551	307
Tochigi	257	2074	56799	295	257
Gunma	0	6	16145	195	7
Saitama	0	5	1800	33	160
Chiba	771	8056	27714	708	2343
Tokyo	0	11	257	20	13
Kanagawa	0	7	279	1	0
Others	343	959	110	1673	33
Total	**105895**	**106974**	**407933**	**31855**	**3559**



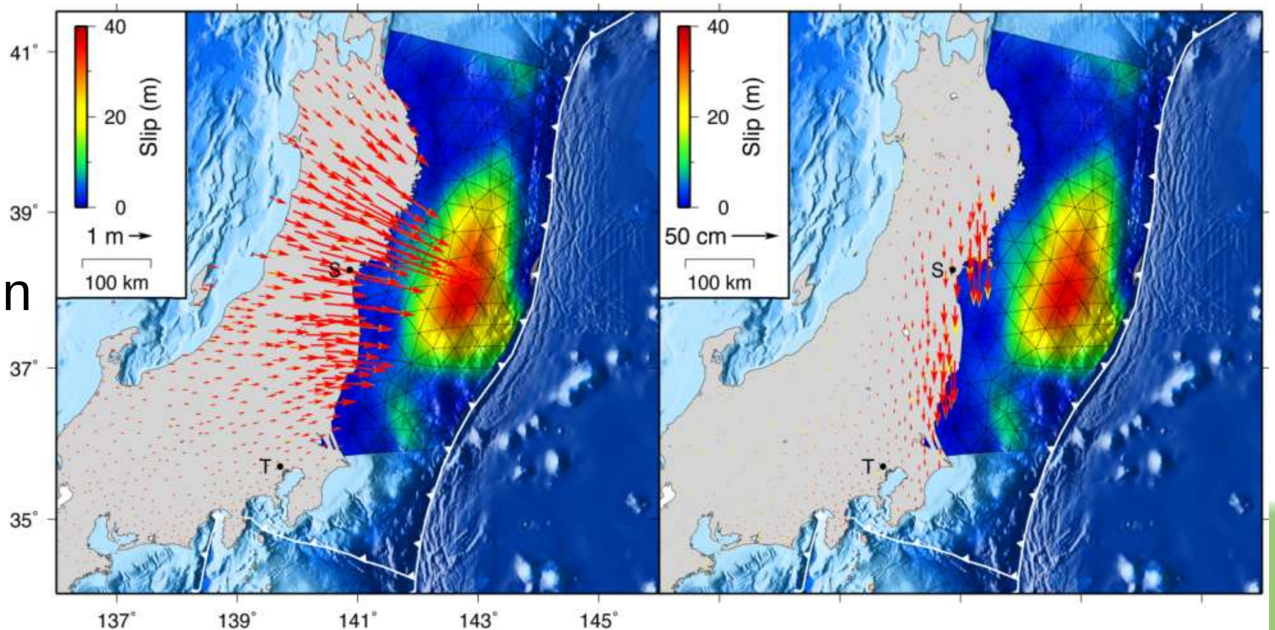
Earthquake and Tsunami

- M_w9.0 mega-thrust earthquake occurred at 2:46:23 pm.
- It triggered tsunamis more than 10 m high, causing immense tsunami damage
- Significant deformation on land – up to 1 m subsidence

Colour contour: slip

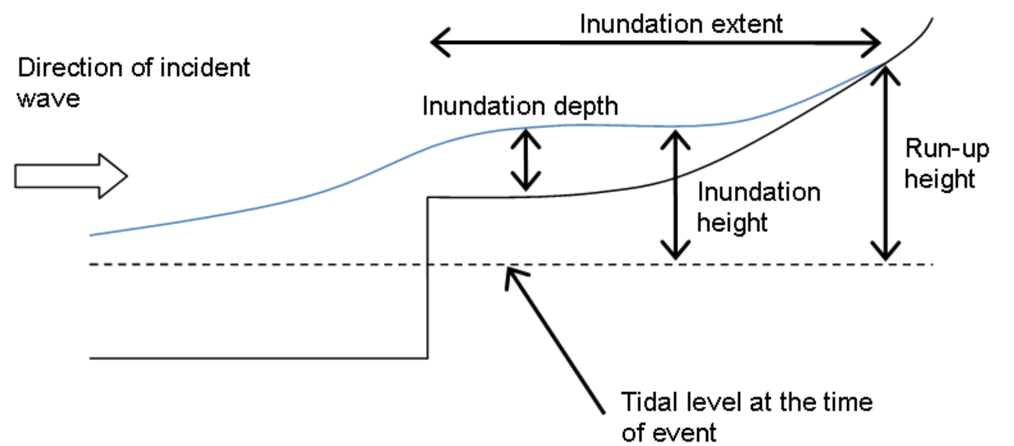
Vector: ground deformation

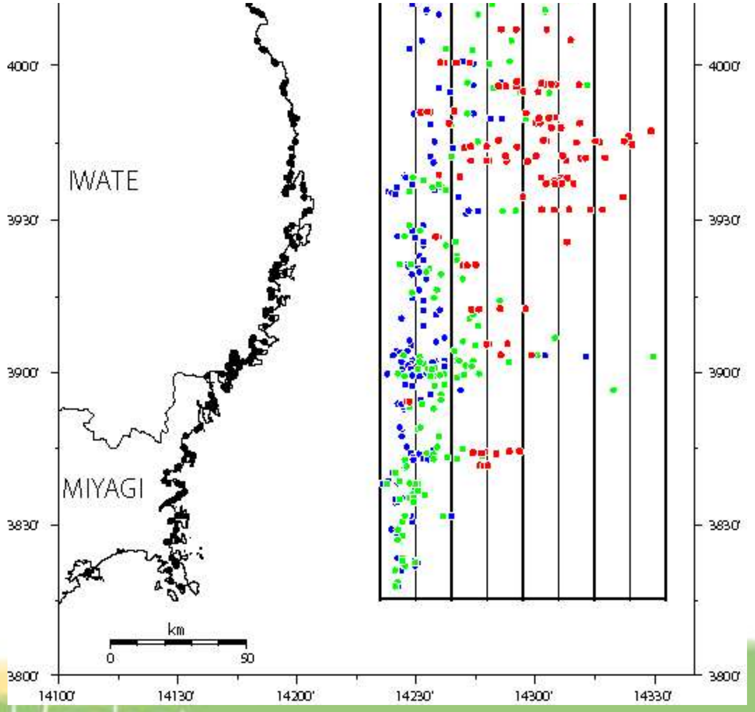
(Simons et al. 2011)

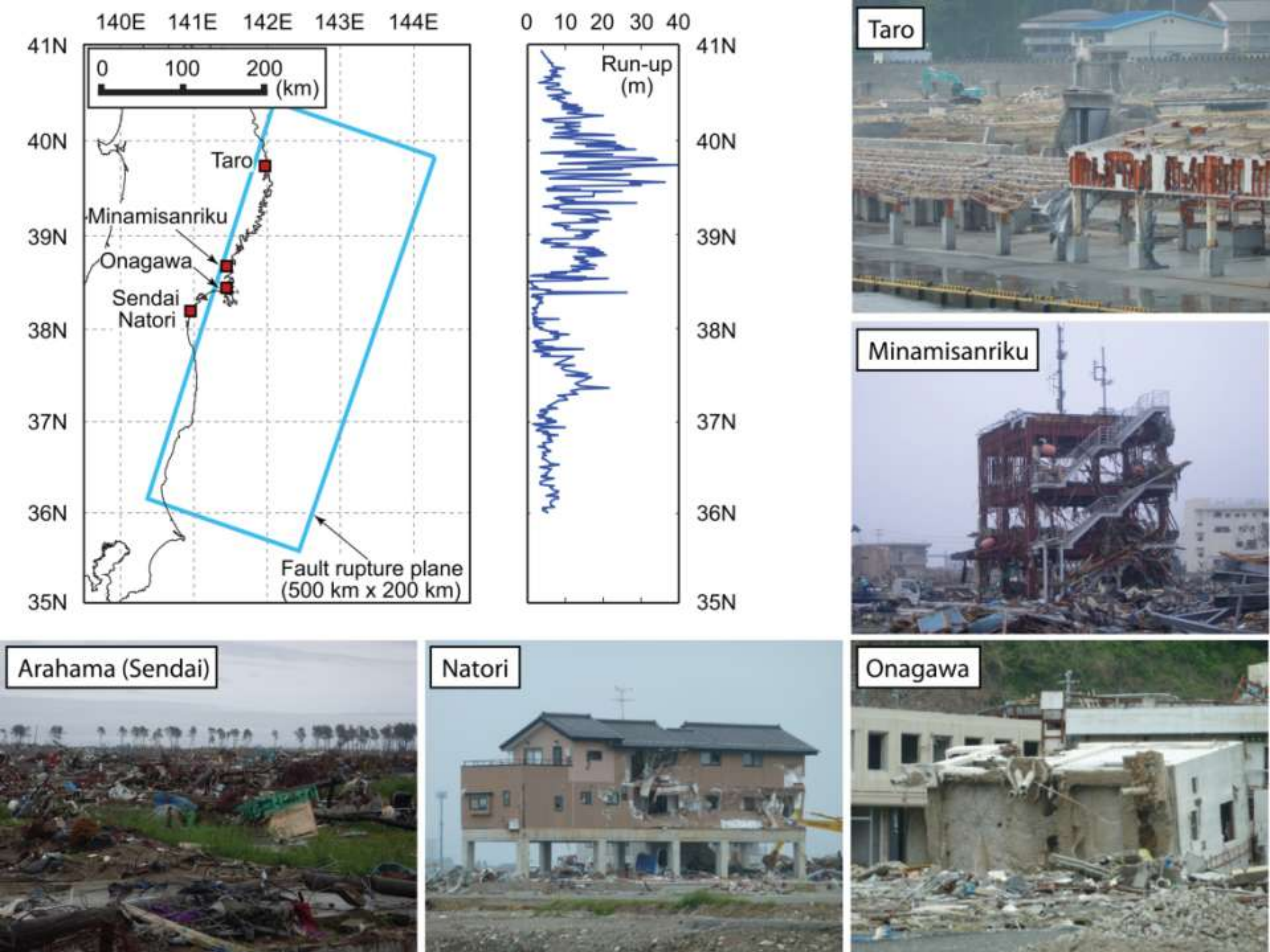


Was This Tsunami Forecasted?

- The Sanriku coast suffered tsunamis in 1896, 1933, and 1960 earthquakes repeated
- The 2011 event generated much larger tsunami waves. Nobody had expected such high tsunami.
- However, historical records indicate such massive tsunamis did occur in the past – e.g. 1611 Keicho tsunami and 869 Jogan tsunami.






140E 141E 142E 143E 144E
41N 40N 39N 38N 37N 36N 35N
0 100 200 (km)
Taro
Minamisanriku
Onagawa
Sendai
Natori
Fault rupture plane
(500 km x 200 km)
0 10 20 30 40
Run-up
(m)
Taro
Minamisanriku
Arahama (Sendai)
Natori
Onagawa

Rikuzen Takata

Sendai

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Taro

- 10-m high walls over 2 km – a well-protected town against tsunami – did not protect the

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Casualty Mitigation

best strategy to reduce the
catastrophic tsunami.

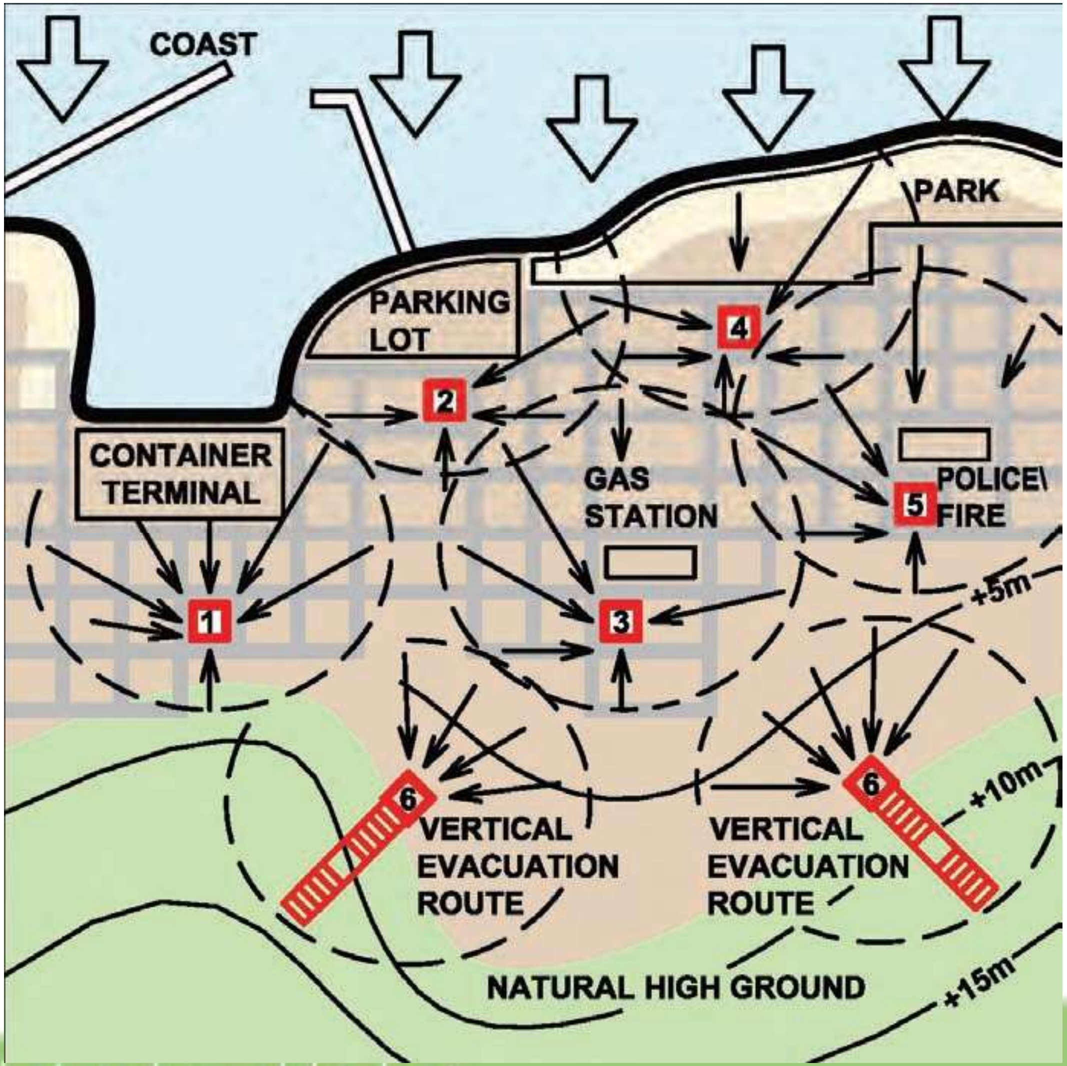
ami protection – Fudai.

structures with higher

- Option 3: Reloca
  Noda.
- Option 4: Combi
  structures

Design of Vertical Evacuation Buildings

- 19000+ death - disproportionate risks for elderly (75% of deaths for age 50+).
- Both horizontal and vertical evacuation must be improved.
- Different strategies for different communities (topography, sea defence, tsunami hazard, demography , etc.)



FEMA (2008)

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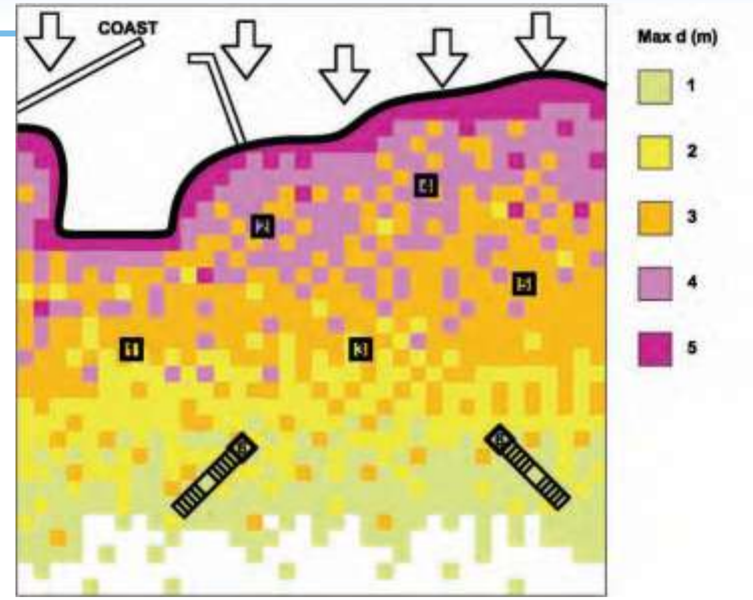
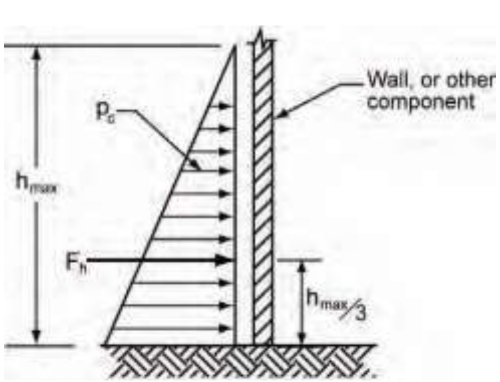
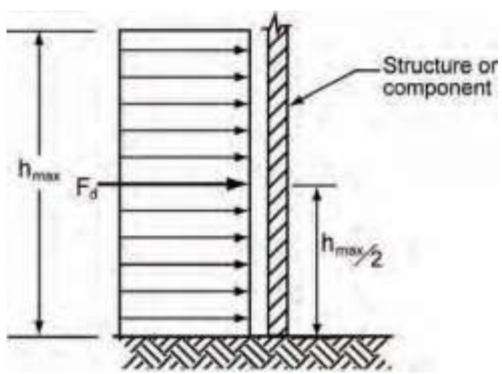
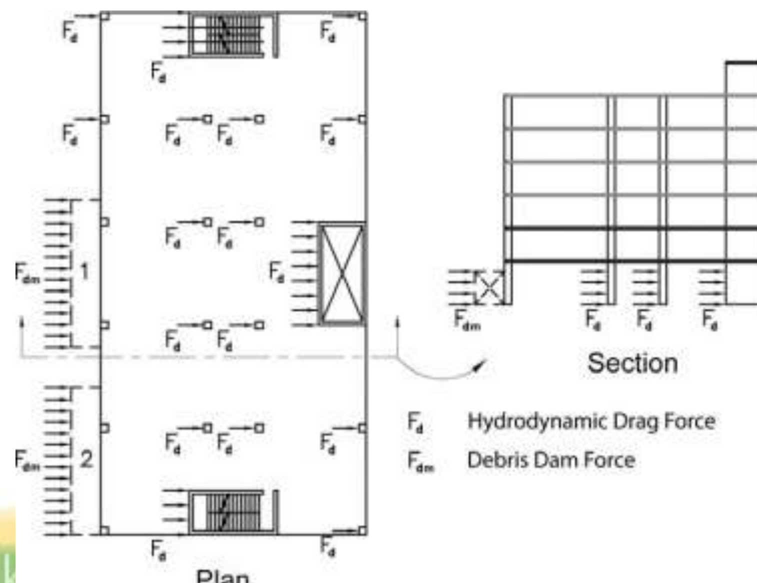
Design of Vertical Evacuation Buildings

- Input information – tsunami height and velocity at a location
- Various forces act on buildings subjected to tsunami: hydrostatic force, hydrodynamic force, debris, buoyant force, etc.





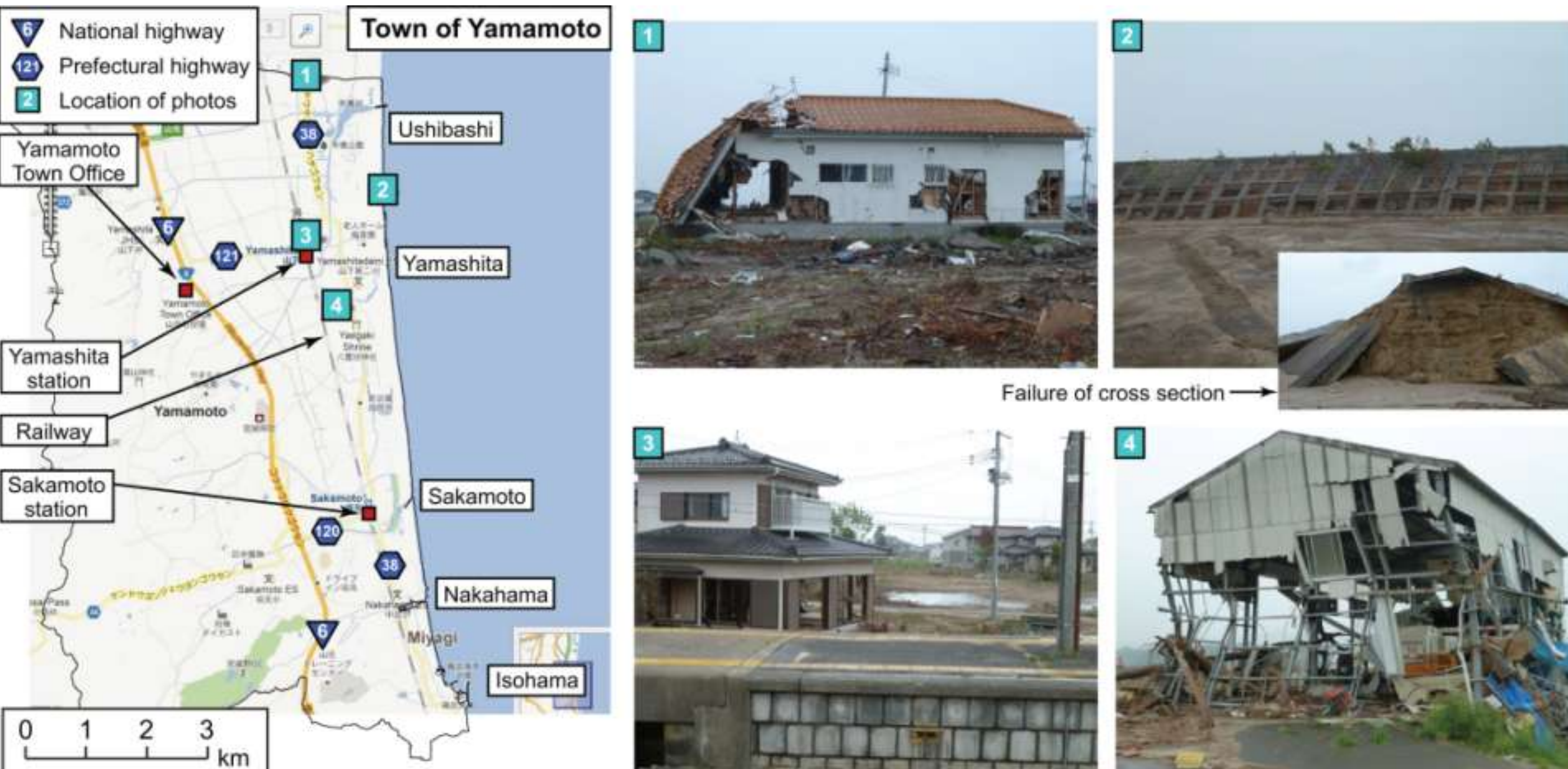




FEMA (2008)

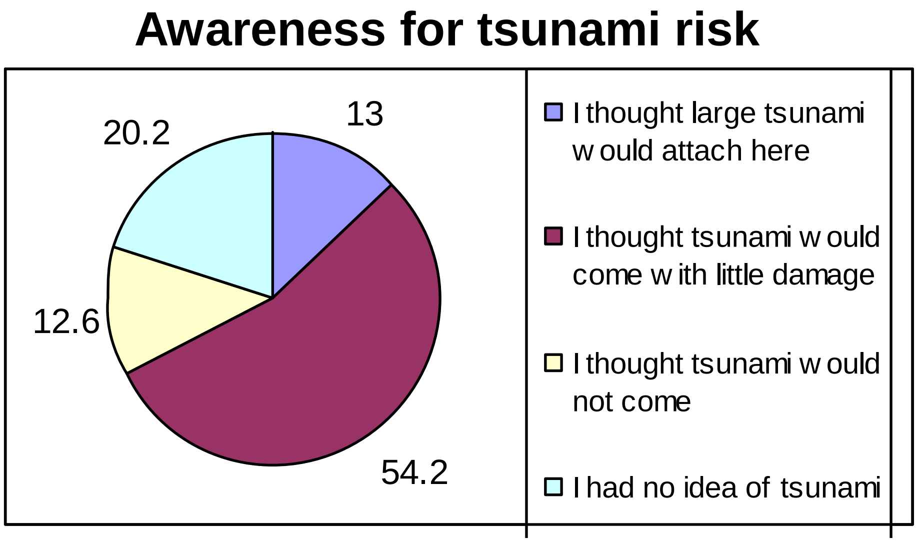
Case Study for Yamamoto (1)

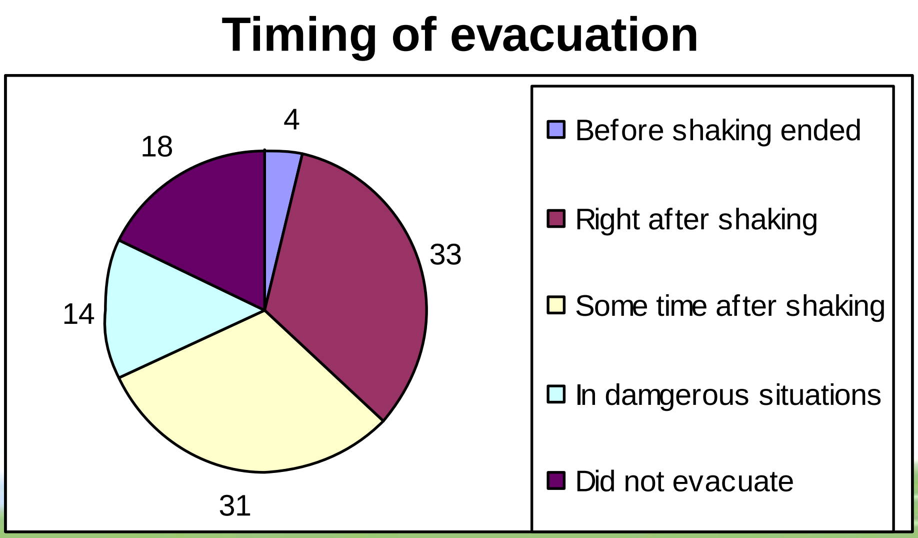
- Coastal plains; Aging society; 676 deaths; only one vertical evacuation building

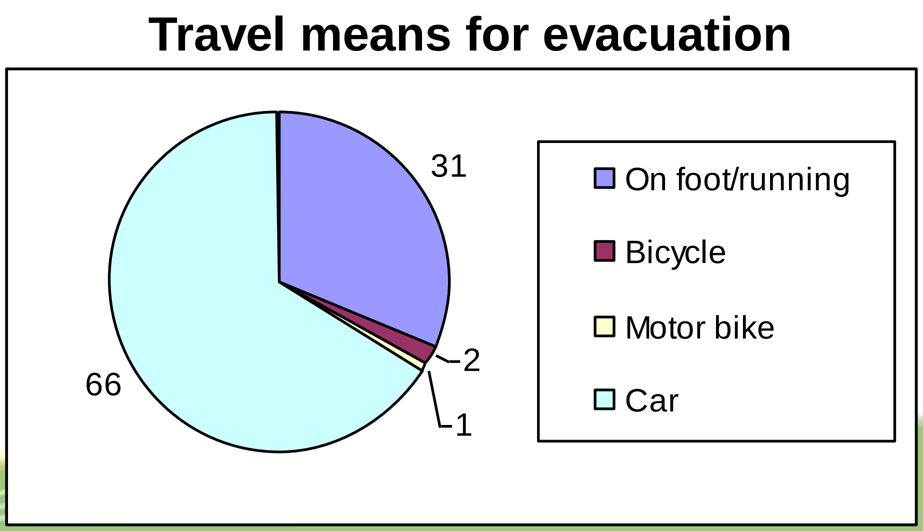


Case Study for Yamamoto (2)

- Post-tsunami survet was conducted in Natori by Murakami et al. (2012)
- Tsunami warning was heard through: radio, TV, municipalities/police
- Use of cars







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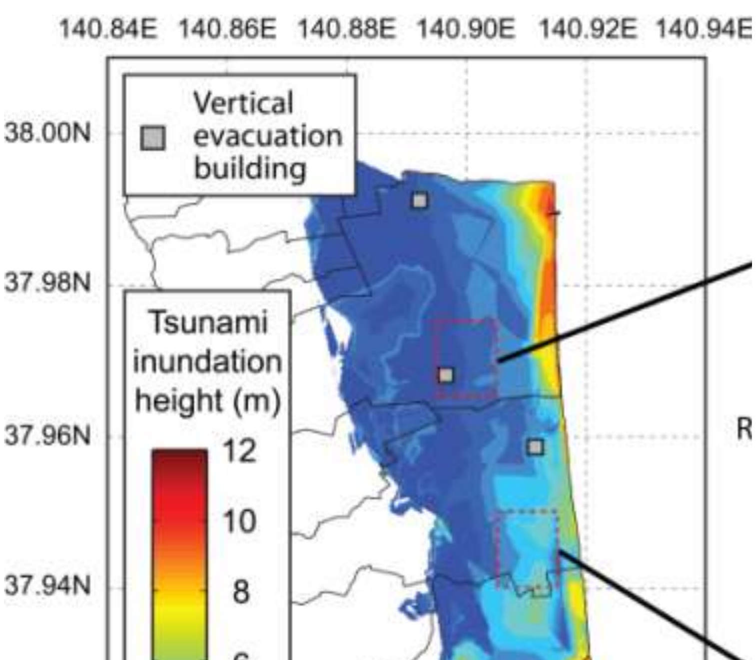
Case Study for Yamamoto (3)

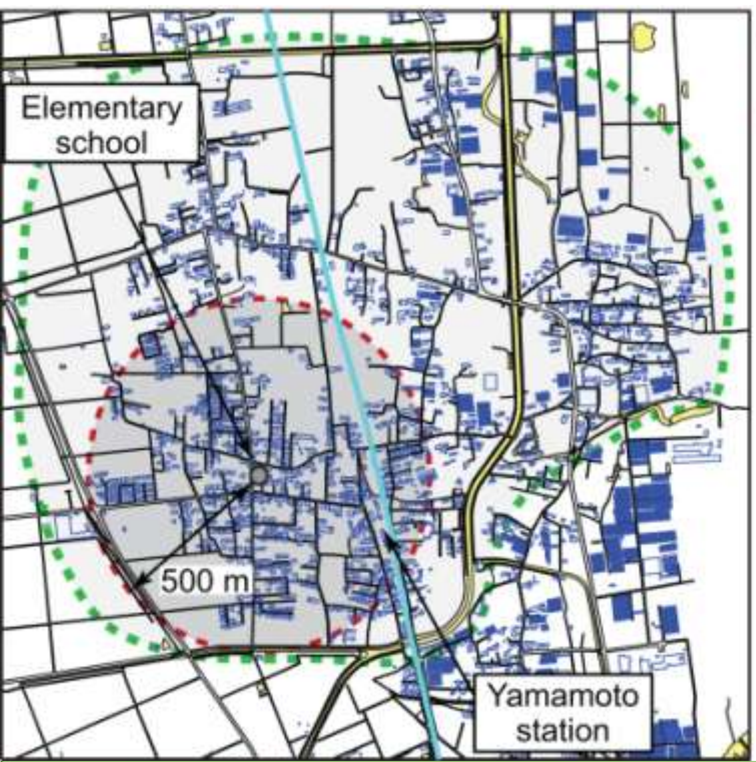


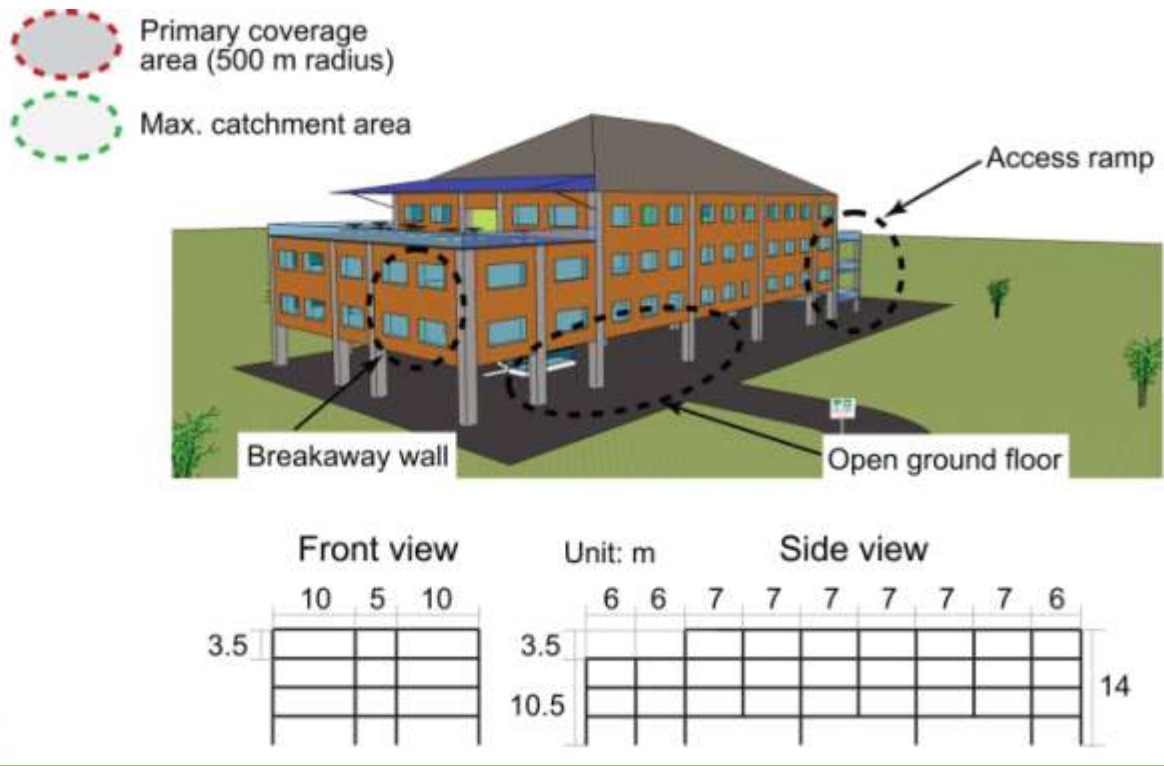
- Five sites for vertical evacuation buildings; Anticipated inundation height plus some freeboard; Coverage area - 500 m radius; Occupancy: local needs for services
- Assume 600 lives saved; 80K GBP/life versus 20-30K GBP/quality year; Cost-effective!

Evacuation building site & occupancy type	Inundation depth (m)	Design tsunami height (m)	Building height (m) [# of storeys]	Covered population [Floor area (m^2)]	Cost (million GBP)
Site 1: Care home	1.95	5.54	14 & [4]	1320 & [2400]	18.1
Site 2: Elem. school	1.85	5.41	14 & [4]	1030 & [1500]	10.82
Site 3: Sports centre	4.09	8.32	14 & [3]	780 & [1000]	6.15
Site 4: Post office	10.49	16.64	17.5 & [5]	740 & [800]	6.89
Site 5: Fish process. plant	7.76	13.09	17.5 & [5]	970 & [1000]	5.53

Case Study for Yamamoto (4)

- 500 m radius primary catchment and extended catchment
- Open ground space, breakaway walls
- Structural design: lateral forces and pile foundation





Key Lessons

- Imagine extreme situations – scenarios!
- Combination of soft and hard measures – resistant structures plus emergency planning/evacuation.
- Multi-layer protection – system robustness & resilience.
- Cooperation among victims, Self-Defence Forces, municipalities, NGOs/NPOs, companies, governments, foreign aids, etc.

Acknowledgements

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