Critical Cause Analysis of Delayed Evacuation in the Great East Japan Earthquake and Tsunami

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ICHARM International Centre for Water Hazard Risk Management under the auspices of UNESCO
## Forensic Investigation on Great East Japan Earthquake and Tsunami (GEJET)

### Meta & Longitudinal Analysis
- Characteristics of tsunami fatalities and losses
- Comparison with historical events

### Critical Cause Analysis
- Analysis of critical causes for human loss expansion caused by delayed evacuation
- Preparation of a question list for human loss vulnerability evaluation

### Scenario Analysis
- Estimation of damages and losses caused by tsunami of a similar magnitude to GEJET in central Japan.
- Identification of issues and proposal of measures to tsunami of an unexpected magnitude
Objectives

- Preliminary effort to conduct FORIN analysis of Great East Japan Earthquake and Tsunami.
- Investigate how the delay in evacuation from tsunami occurred, and how it lead to enormous human losses.
- Identify critical points for considering vulnerability of communities against human losses caused by delayed evacuation from tsunami.

Outline

1. Overview of the Great East Japan Earthquake and Tsunami (GEJET)
2. Critical causes analysis of human losses due to delayed evacuation
3. Case Study of Rikuzentakata
4. Conclusion
1. Great East Japan Earthquake and Tsunami (GEJET)

- M9.0 earthquake occurred on March 11, 2011 at 14:46
- Massive ground motion was observed throughout Japan
- Mega-tsunami of about 1,000 year return period and subsidence led to enormous damages
- Complex disaster (earthquake, tsunami, nuclear accident)
- Historic Tsunami Events in the region
  - 1897: [M8.5] 21,959 dead
  - 1933: [M8.1] 3,064 dead or missing

Japan Meteorological Agency
Overview of Damages

- Inundated area by tsunami: 561km²
- Human casualties: 15,829 dead, 3,745 missing, 5,942 injured (as of Oct 25)
- Building damages: 118,790 completely destroyed, 184,343 half destroyed, 280 burned down, 10,961 inundated (above floor), 13,867 inundated (below floor)
- Agricultural land losses: 23,600ha
- Direct damages to infrastructure stock: approx. 16.9 trillion yen (US$200 billion, estimated by cabinet office, not including damages caused by nuclear accident)

National Police Agency (As of Oct 25, 2011)
2011 White Paper on Disaster Management

Fire and Disaster Management Agency (As of Sept 9, 2011)
Human Losses

- 92.4% of people died in Iwate, Miyagi and Fukushima lost their lives due to tsunami.

Tsunami was the main cause of death

Death causes in GEJET (Iwate, Miyagi & Fukushima)
Source: 2011 White paper on disaster management

65% of fatalities were 60 years or older

Age structure of population and people died in GEJET (Iwate, Miyagi & Fukushima)
## 2. Critical cause analysis of human losses due to delayed evacuation

### Why were so many people not able to escape from the tsunami?

<table>
<thead>
<tr>
<th>Strong ground motion (seismic intensity of 6 or greater)</th>
<th>Large tsunami attack could have been conceivable by people?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quake occurred during the day. 30 minutes to 2 hours of time available before tsunami arrived.</td>
<td>Evacuation actions could have been easily taken?</td>
</tr>
<tr>
<td>Tohoku region (especially Iwate) have experienced tsunami disasters repeatedly in the past</td>
<td>Lessons learned in the past not effectively utilized?</td>
</tr>
<tr>
<td>Coastal levees had been constructed along much of the coast line</td>
<td>Misperception about tsunami safety existed (people thought tsunami disaster will never occur)?</td>
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</tbody>
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The critical points for human losses and delayed evacuation were analyzed by reviewing various reports published after GEJET.
**Magnitude of Tsunami in GEJET**

% of people died or missing in inundated area

<table>
<thead>
<tr>
<th>%</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0~1%</td>
<td>Blue</td>
</tr>
<tr>
<td>1~3%</td>
<td>Cyan</td>
</tr>
<tr>
<td>3~5%</td>
<td>Green</td>
</tr>
<tr>
<td>5~10%</td>
<td>Yellow</td>
</tr>
<tr>
<td>&gt;10%</td>
<td>Pink</td>
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</tbody>
</table>

(Number of fatalities & missing) / (population in inundated area)

**Tsunami height exceeded twice the height of coastal levees**

- **Tarou**: levee height 10m, tsunami height 15.5m, run-up height approx. 38m
- **Otsuchi**: levee height 6.4m, tsunami height 12.9m
- **Rikuzentakata**: levee height 6.15m, tsunami height 16.4m
- **Onagawa**: levee height 4.4m, tsunami height 15.9m

※ levee height and tsunami trace height near the levee in front of the coastal cities and towns were plotted from the maps produced by the Tohoku regional bureau of MLIT.
Effectiveness of Structural Measures

Structural measures proved to be effective and protected lives in certain areas

- **Hirono, Iwate**
  - Coastal levee (T.P.+12.0m) was higher than the tsunami height (tsunami run-up height T.P.+9.5m)

- **Fudai, Iwate**
  - City located far from the coast was protected by the gate.

Source: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
Effectiveness of Structural Measures

- The greater the tsunami height compared to the levee height the greater the human losses.
- Many other factors influenced the extent or severity of human losses.

※ levee height and tsunami trace height near the levee in front of the coastal cities and towns were plotted from the maps produced by the Tohoku regional bureau of MLIT.
% Human loss based on the data announced on Sept 9 2011 by the Fire and disaster Management Agency
Flow of Human Losses due to delay in evacuation

Flow of human losses due to delay in evacuation in case of tsunami to identify the critical points for human loss expansion.

Fundamental action to be taken by people

**Critical Point 1**
Immediate recognition of necessity to evacuate

- Evacuated
  - self-judged
  - info-reactive
  - follow others

- Critical Point 3
  - Evacuation actions

- Warning accessible

**Critical Point 2**
Accurate evacuation warning/information

- Did not evacuate

**Critical Point 4**
Obstacles during evacuation

- Did not arrive at evacuation shelters

**Critical Point 5**
Safety of evacuation shelters

- Evacuation shelter not stricken by tsunami

**Critical Point 6**
Detection of danger and progressive evacuation

- Escaped from tsunami

- Evacuation shelter stricken by tsunami

- Caught by tsunami
CP1 Immediate recognition of necessity to evacuate

Critical Point 1
Immediate recognition of necessity to evacuate

Evacuated
self-judged

About half of the people who survived tsunami evacuated immediately after the earthquake.

Timing of Evacuation

- Immediately evacuated: 57%
- Evacuated after completing other actions: 31%
- Evacuated only after noticing that tsunami was approaching: 11%
- Did not evacuate (already in safe area): 1%

Total N=870

Source: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
Even among those who survived, many were not aware of tsunami risks.

- People who evacuated only after noticing that tsunami was approaching didn’t evacuate immediately because “tsunami didn’t occur in past earthquakes” or “tsunami never came up to their mind” ※1
- In Miyagi, about half of the people survived thought tsunami wouldn’t come or didn’t think about tsunami. Only 4% had seen tsunami hazard maps. ※2

Source:
※1: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
※2: Survey Research Center “宮城県沿岸部における被災地アンケート” May 2011
CP1 Immediate recognition of necessity to evacuate

Critical Point 1
Immediate recognition of necessity to evacuate

Because the tsunami occurred during the day, many were away from home. Instead of evacuating people went searching for their family members.

- Many of the people that didn’t immediately evacuate were out of their homes. Instead of evacuating they went back home or went out to look for their families. ※1
- The disaster occurred during the day time when family members were scattered. People worried about the safety of their family and moved immediately to get together with their family members. ※2

Source:
※1: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
※2: Survey Research Center “宮城県沿岸部における被災地アンケート” May 2011
Immediate recognition of necessity to evacuate

- Risk or danger of tsunami and necessity to evacuate not recognized by all people.
- Many prioritized actions to search for their family members over evacuation.
- Disaster education in schools proved very effective.

Critical Point 1
Immediate recognition of necessity to evacuate

Evacuated
self-judged

Disaster education and evacuation procedures in schools proved to be very effective, saving lives of school children.

% Human loss in inundated area

Iwate

- Miyako
- Ofunato
- Rikuzentakata
- Kamaishi
- Otsuchi
- Yamada

Very small human loss rate in ages of 5 to 14

Source:
※1: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
※2: Survey Research Center “宮城県沿岸部における被災地アンケート” May 2011
CP2: Accurate evacuation information

- Accurate and most up-to-date tsunami warning information was not accessible for many people due to power outage, etc.
- Underestimated preliminary forecast lead to misconception that it is “safe”.

Critical Point 1
Immediate recognition of necessity to evacuate

Evacuated
self-judged

Warning accessible

Critical Point 2
Accurate evacuation warning/information

Warning not accessible

- Average time required to obtain tsunami warning or advisory was 16.4 minutes. ※1
- In tsunami prone areas 13% did not know that tsunami warning was announced. ※1
- Many of usual communication methods became inaccessible due to power outage, overwhelmed phone lines, etc ※2
- Underestimated preliminary forecast was misinterpreted as “safe”. ※3
- Due to power outage, updated information was not accessible. ※3

Source:
※1 weathernews “Survey Results of Great East Japan Earthquake and Tsunami” (April 2011)
※2 Crisis and Environment Management Policy Institute “Preliminary Report on the Survey on Tohoku Pacific Ocean Earthquake and Tsunami” (May 2011)
※3 Japan Meteorological Agency “Issues with regard to improvement of tsunami warning “ (June 2011)
CP3: Evacuation actions

✅ Evacuation warnings and evacuation advices by neighbors and families triggered evacuation actions for many people.

- In average it took 17 minutes to begin evacuation. Almost 80% evacuated with others, 53% with their family members. ※1
- Among people who heard evacuation warnings clearly from disaster management radio, 70 to 80% felt the necessity to evacuate. ※2
- Many people lost their lives while convincing or guiding other people to evacuate, including over 300 fire and disaster department staffs, fire fighters and police officers delivering evacuation warnings or guiding evacuation. ※3

Source:
※1: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
※2: Survey Research Center “宮城県沿岸部における被災地アンケート” May 2011
※3: Fire and Disaster Management Agency, National Police Agency
CP4: Obstacles during evacuation

- **Critical Point 1**: Immediate recognition of necessity to evacuate
- **Critical Point 2**: Accurate evacuation warning/information
- **Critical Point 3**: Evacuation actions
- **Critical Point 4**: Obstacles during evacuation

- **Evacuated self-judged info-reactive follow others**
- **Arrived at evacuation shelters**
- **Did not arrive at evacuation shelters**
- **Did not evacuate**

Many evacuated using cars and got trapped in traffic.

- 60% evacuated by cars and 1/3 were caught in traffic. ※1
- Many used cars because they thought otherwise they wouldn’t make it, or they wanted to evacuate with family members. ※1
- In Miyagi, many people older than 60 or women used cars. Among those caught in traffic, only 7.3% changed the mean of transportation. ※2

Source:
※1: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
※2: Survey Research Center "宮城県沿岸部における被災地アンケート" May 2011
CP4: Obstacles during evacuation

- Use of cars during evacuation caused traffic congestion and many got trapped.
- Pre-installed tsunami emergency routes in schools proved very effective.

**Critical Point 1**
Immediate recognition of necessity to evacuate

**Warning accessible**

- Evacuated
  - Self-judged
  - Info-reactive
  - Follow others

- Arrived at evacuation shelters

**Evacuation routes played big role in securing safety of people, especially school children.**

- **Critical Point 2**
  Accurate evacuation warning/information

- **Critical Point 3**
  Evacuation actions

- **Warning not accessible**

- Did not evacuate

- **Did not arrive at evacuation shelters**

- **Critical Point 4**
  Obstacles during evacuation

- **Source:**
  Asahi Newspaper
  Iwaizumi Town Paper (April 2011)
CP5: Safety of evacuation shelters

✓ Safety (location and structural) of evacuation shelters was insufficient in some cases

- In 11 cities of Iwate prefecture 48 evacuation shelters out of 411 were inundated. ※1
- In Onagawa Town, reinforced concrete buildings often used as evacuation shelters were collapsed from the foundation. ※2

Source:
※1 Kahoku Shinpo (April 14, 2011)
※2 Japanese Society of Civil Engineers Emergency Investigation Group Report
CP6: Detection of danger and progressive evacuation

Many evacuated to safer location regardless of the designated shelters.

Among those who evacuated from tsunami in Miyagi, 60.8% evacuated from the primary evacuation shelter to the next. Among them 55.5% said the first shelter was stricken by tsunami. ※1

For most people the primary evacuation shelter was “publicly designated shelter such as community centers and schools”. About 40% moved further to evacuate to higher elevation or safer facilities. ※2

Source:
※1: The Expert Panel on Earthquake and Tsunami Countermeasures in Light of the Lessons Learned from the 2011 Tohoku-Pacific Ocean Earthquake
※2: Survey Research Center “宮城県沿岸部における被災地アンケート” May 2011
Check List to assess Human Loss Vulnerability

CP1: Immediate recognition of necessity to evacuate

- Are there ways to disseminate tsunami warnings or evacuation information?
- Are there ways to disseminate information at once?
- Is information accessible during power outage?
- Is the risk of tsunami recognized from past tsunami disasters or hazard maps?
- Are methods of safety confirmation among family members ensured?

CP2: Accurate evacuation warning/info

- Are there ways to disseminate tsunami warnings or evacuation information?
- Are there ways to disseminate information at once?
- Is information accessible during power outage?

CP3: Evacuation actions

- Is information disseminated received/understood by people appropriately?
- Are there community efforts to promote evacuation among neighbors?
- Is the safety of officers providing evacuation guidance ensured?

CP4: Obstacles during evacuation

- Is the evacuation route safety ensured?
- Are people aware of the location of evacuation shelters?
- Are evacuation shelters located in ways so that people can walk to shelters?
- Are there emergency routes secured that ensure immediate evacuation to higher elevation?

CP5: Safety of evacuation shelters

- Is the safety of evacuation shelter ensured (height & structural safety)?
- In flat areas far from hills, are there safe evacuation shelters (such as tsunami evacuation buildings) designated?

CP6: Detection of danger and progressive evacuation

- Are people provided with disaster education to evacuate to safer places regardless of designated evacuation shelters?
- Can the real time tsunami information be obtained to detect danger early?
3. Case Study of Rikuzentakata City

Approx. 2,000 persons (10% of total population) are dead or missing in Rikuzentakata

Buildings destroyed 3,159
Dead and missing 2,191
Inundated area 1,300ha
Population in inundated area 16,640
# households in inundated area 5,592

Rikuzentakata City Hall was devastated by tsunami

Tsunami submerged up to 4th floor
Flow of Human Losses in Rikuzentakata

Lack of awareness regarding tsunami risks lead to delay in evacuation.

- Only 33 out of 180 immediately evacuated. Out of 33 only 1 died. ※1
- Among those who didn’t immediately evacuate half didn’t think tsunami would arrive to their location ※1
- Among 147 that didn’t immediately evacuate 1/3 (42) died. ※1

Source:
※1: 陸前高田市における東日本大震災大津波襲来時の住民行動—将来の防災へ向けて— ICHARM, UNESCAP
Flow of Human Losses in Rikuzentakata

Safety of evacuation shelters was not secured.

- Examination of bodies indicated that many had finished evacuation or were in the midst of evacuation. ※2
- Number of designated evacuation shelters were located within the inundated area and many died at the evacuation shelters. ※1
- Out of 68 primary evacuation shelters, 35 were inundated by tsunami. ※2

Source:
※1: 陸前高田市における東日本大震災大津波襲来時の住民行動－将来の防災へ向け－ ICHARM, UNESCAP
※2: Examination of bodies indicated that many had finished evacuation or were in the midst of evacuation. Number of designated evacuation shelters were located within the inundated area and many died at the evacuation shelters. Out of 68 primary evacuation shelters, 35 were inundated by tsunami.
Flow of Human Losses in Rikuzentakata

Human loss of younger generations could be explained by the fact that many lost their lives at evacuation shelters upon completion of evacuation.
Critical Causes for Human Losses in Rikuzentakata

- Lack of awareness regarding tsunami risks
  - Hazard maps
  - Urban development in areas of high tsunami risks
- Inappropriate designation of evacuation shelters
4. Conclusion

- The critical causes for human losses vary depending on the physical settings and social characteristics of the communities, and the extent of tsunami prevention/preparedness measures (both structural and non-structural).
- The current FORIN template is useful in obtaining the in-depth and exhaustive picture of the phenomenon of the disaster and its impact. But to do this in full scale it would require much time and resources.
- In order to identify critical causes or bottlenecks for certain area, utilization of hierarchical check list as prepared in this study could be useful.
- An investigation sheet consisting of check list can be prepared for different entities (administrator, community, general public, etc.) to measure their vulnerability against disasters. Such tool could assist identifying weakness or necessity for future measures.
Thank you very much
Example of human loss vulnerability review sheet (municipality)

CP1: Immediate recognition of necessity to evacuate

- Are there ways to disseminate tsunami warnings or evacuation information?
- Is information accessible during power outage?
- Is information disseminated/received/understood by people appropriately?
- Are there community efforts to promote evacuation among neighbors?
- Is the safety of officers providing evacuation guidance ensured?
- Is the evacuation route safety ensured?
- Are people aware of the location of evacuation shelters?
- Are evacuation shelters located in ways so that people can walk to shelters?
- Are there emergency routes secured that ensure immediate evacuation to higher elevation?
- Is the safety of evacuation shelter ensured (height & structural safety)?
- In flat areas far from hills, are there safe evacuation shelters (such as tsunami evacuation buildings) designated?
- Are people provided with disaster education to evacuate to safer places regardless of designated evacuation shelters?
- Can the real time tsunami information be obtained to detect danger early?

CP2: Accurate evacuation warning/info

- Are there ways to disseminate information at once?
- Is accurate evacuation information accessible?

CP3: Evacuation actions

- Did not evacuate
- Evacuated
  - Self-judged
  - Info-reactive
  - Following others

CP4: Obstacles during evacuation

- Did not arrive at evacuation shelters
- Arrived at evacuation shelters

CP5: Safety of evacuation shelters

- Evacuation shelter not stricken by tsunami
- Evacuation shelter stricken by tsunami
- Escaped from tsunami
- Caught by tsunami
In the GEJET many infrastructure services were impacted in enormous scale. Propagation of damages among infrastructure and its impact to socio economic activities are critical issue.

By knowing critical points in damage propagation, effective measures could be implemented to mitigate propagation of damages and to minimizing extent of impacts.

Further questions could be added to the FORIN Questions List.

- What were the consequences of breakdown or malfunctioning of infrastructure networks (e.g., electricity, water supply, sewerage, transportation, communication, health services, educational services, etc)?
- How did the effect on an infrastructure network propagate to another infrastructure network?
- How were the economic activities of the affected area impacted and how did it propagate to other areas/regions?
- What actions were taken in order to compensate the infrastructure or service network failure.
- How were the infrastructure or service networks restored?