東日本大震災・津波の記録

Record of 2011 Great East Japan Earthquake/Tsunami

政策研究大学院大学
GRIPS
NATIONAL GRADUATE INSTITUTE FOR POLICY STUDIES

March 2015 年 3 月

INTERNATIONAL INSTITUTE OF SEISMOLOGY & EARTHQUAKE ENGINEERING
BRI

Joint Project by 政策研究大学院大学・建築研究所共同事業

National Graduate Institute for Policy Studies (GRIPS) DM Program & International Institute of Seismology and Earthquake Engineering (IISEE) of the Building Research Institute (BRI), JAPAN

Iwate, BRI 2011.4

All Photos provided by

BRI, IISEE and GRIPS

Mainly Hiroshi Fukuyama, Shoichi Ando, Yushiro Fujii and other IISEE members

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Otsuchi, Iwate, by Ando, BRI-GRIPS 2011.4

Onagawa, Miyagi, by Ando, BRI-GRIPS 2011.4

Iwaki, Fukushima, by Fujii, BRI 2011.4

“Record of 2011 Great East Japan Earthquake” by GRIPS and IISEE/BRI
政策研究大学院大学 GRIPS 及び(独)建築研究所 IISEE による「**東日本大震災の記録**」

1. 2012 IPRED5 Site Visit to 2011 Great East Japan Eq. areas
2012 年 IPRED 第 5 回会合 東日本大震災被災地への現地視察

1 Kesennuma city, Miyagi 宮城県気仙沼市

２ MLIT Tohoku 東北地方整備局

３ Onagawa town 宮城県女川町

5th IPRED “Record of field visit” 第 5 回(2012 年 6 月) IPRED 会合の際の現地調査記録 2

４ Onagawa town 宮城県女川町

５ Onagawa town 宮城県女川町

６ Ishinomaki city 宮城県石巻市

７ Ishinomaki city 宮城県石巻市

８ Ishinomaki city 宮城県石巻市

９ Ishinomaki city 宮城県石巻市

１０　Ishinomaki city 宮城県石巻市

１１ Minami-sanriku town 南三陸町

１２　Minami-sanriku town 南三陸町

１３ Minami-sanriku town 南三陸町

１４ Minami-sanriku town 南三陸町

１５ Minami-sanriku town 南三陸町

5th IPRED “Record of field visit” 第 5 回(2012 年 6 月) IPRED 会合の際の現地調査記録 ４

１６ Minami-sanriku town 南三陸町

１７ Kesen-numa city 宮城県気仙沼市

１８ Kesen-numa city 宮城県気仙沼市

１９ Kesen-numa city 宮城県気仙沼市

IPRED 5 Overseas Participants 第 5 回 IPRED 参加メンバー（主に海外メンバー）

Badaoui Rouhban:	UNESCO Director, Unit for Natural Disasters, UNESCO
Carlos Zavala:	Director, Japan-Peru Center (CISMID), Peru
Edgar Armando Peña:	Professor, Universidad de El Salvador
Faruk Karadogan:	Professor, Former Rector, Istanbul Technical Univ., Turkey
Jair Torres:	UNESCO, Unit for Natural Disasters
Radu Vacareanu:	Vice-Rector, Technical Univ. of Civil Engineering, Romania
Raul Alvarez Medel:	Professor, Universidad Catolica de Chile
Salah Mahmoud:	Dept. of Geodynamics, National Research, NRIAG, Egypt
Sutadji Yuwasdiki:	Head, Laboratory of Structure, RIHS, Indonesia
Tanatkan Abakanov:	Director, Institute of Seismology, Kazakhstan
Yasuo Katsumi:	UNESCO Programme Specialist, Unit for Natural Disasters,
Yuji Ishiyama:	Professor Emeritus, Hokkaido University

2. Comparison of Before and After 2011 Great East Japan Eq.
2011 年 3 月 11 日　東日本大震災の被災前と被災後の比較写真

Taro area, Miyako city, Iwate 岩手県宮古市田老地区 (2010-2014)　1

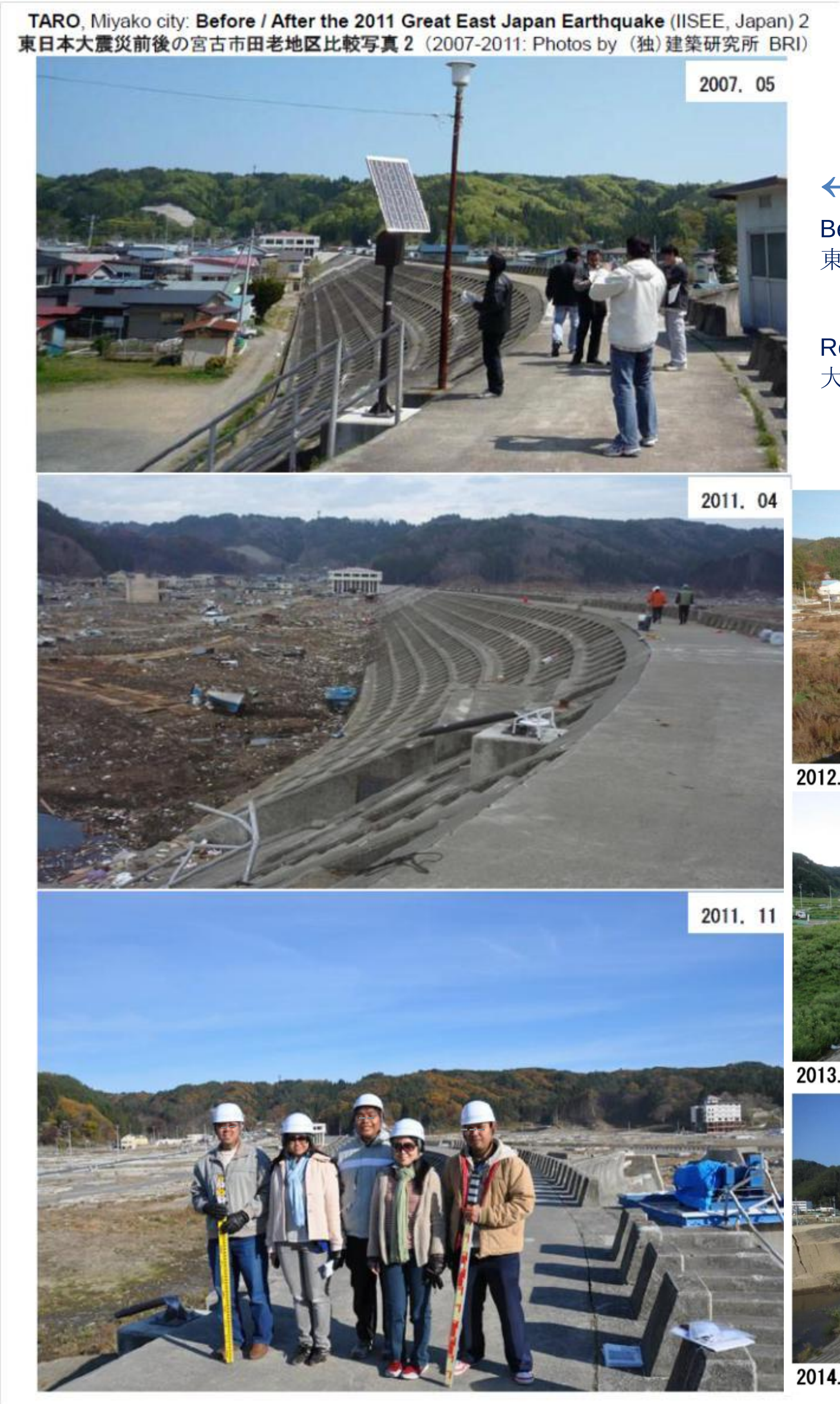
←

Before and After Damage
東日本大震災前後比較写真

Reconstruction Processes
大震災の復興プロセス写真

↓

Taro area, Miyako city, Iwate 岩手県宮古市田老地区 (2010-2014) 2



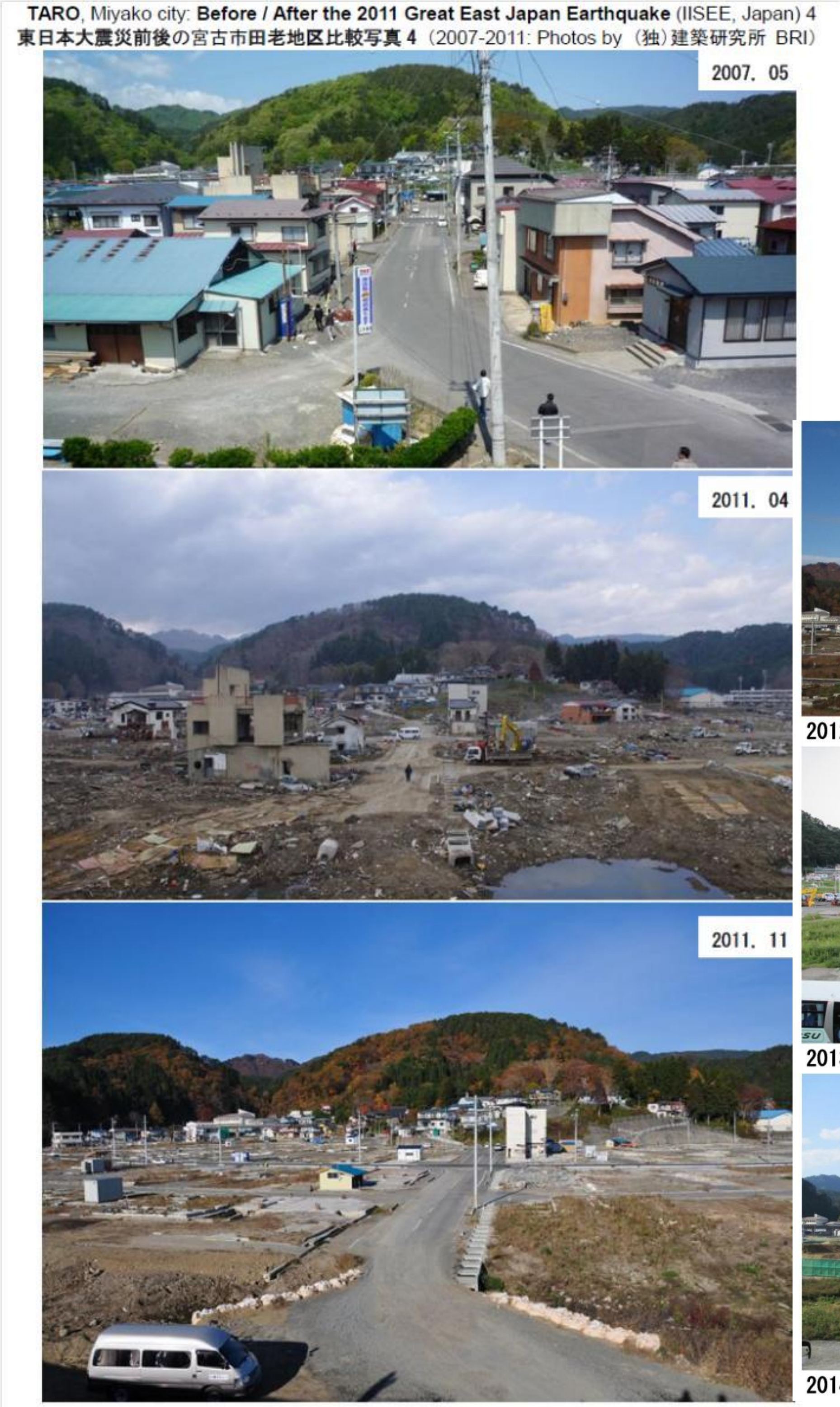
←

Before and After Damage
東日本大震災前後比較写真

Reconstruction Processes
大震災の復興プロセス写真

↓

Taro area, Miyako city, Iwate 岩手県宮古市田老地区 (2010-2014) 3



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Before and After Damage
東日本大震災比較写真

Reconstruction Processes
大震災の復興プロセス写真

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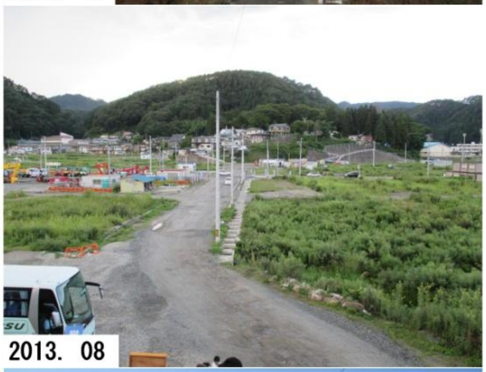


Comparison of After (1-6 month), 2011 Great East Japan Earthquake
2011 年 3 月 11 日　東日本大震災の被災後の比較写真（1 カ月後と半年後）

Cases of Center of Onagawa Town, Miyagi Prefecture 宮城県女川町中心部の事例

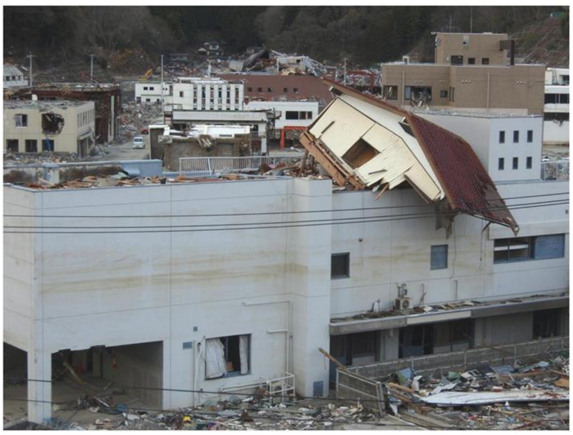
Left photo: one month after (2011.4)　⇔　**Right photo**: 6 months after (2011.9)




Cases of Center of Onagawa Town, Miyagi Prefecture 宮城県女川町中心部の事例

Left photo: one month after (2011.4) ⇔ **Right photo**: 6 months after (2011.9)

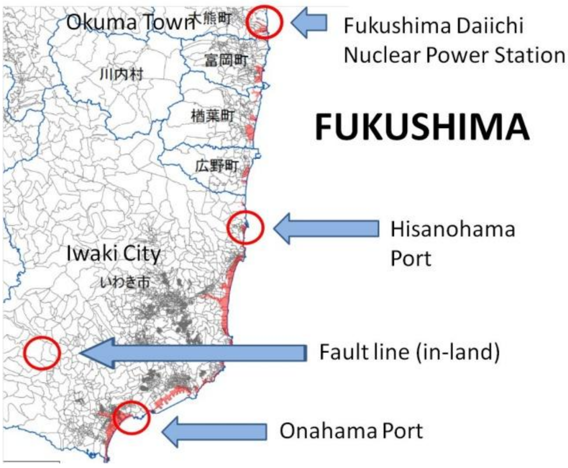





3. 2011.03-09, 2011 Great East Japan Eq. and Tsunami hit area
2011 年 ～ 2014 年　東日本大震災による震害と津波被害の写真

Field Investigation 1 現地調査 1 （Iwaki city, Fukushima 福島県いわき市）**21 Apr. 2011**

１ Hisano-hama, Iwaki　いわき市久之浜



２ Iwaki Onahama Port いわき市小名浜港

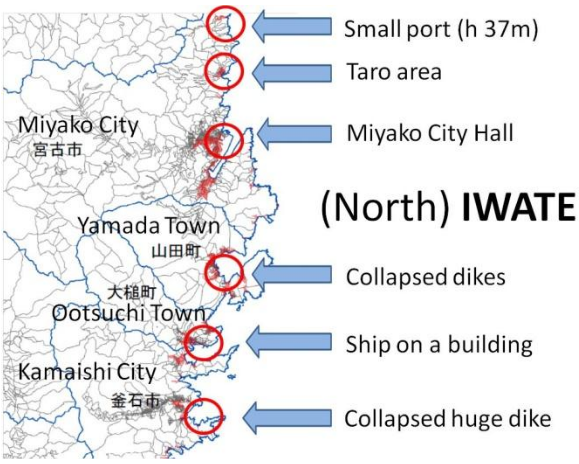
３ Iwaki City Hall　いわき市庁舎

４ Idosawa Fault 11 Apr. いわき井戸沢断層

５ Idosawa Fault 11 Apr. いわき井戸沢断層

Field Investigation 2 現地調査２（Northern part, Iwate 岩手県北部）**27 Apr. 2011** + 2011.9

１ Kuwagasaki, Miyako 宮古市鍬ヶ崎



２ Miyako Koborinai port 宮古市小堀内漁港

３View from Miyako city hall 宮古市庁舎より

４ Taro Kanko Hotel 田老観光ホテル

５ Taro Port, Miyako city 宮古市田老港

６ Kamaishi Port, Iwate　岩手県釜石港（以下 2011.09）

７ Yamada town, Iwate　岩手県山田町

８ Sea-wall, Kamaishi Port 釜石港防波堤

９ Rikuzen-takata city 陸前高田市

１０ Kamaishi Port 釜石港（2011.09）

Field Investigation 3 現地調査３（Eastern part, Miyagi 宮城県）**28 Apr. 2011**+ 9 Apr. 2011

1 RC wall of Onagawa town, Miyagi 宮城県女川町 RC 壁 以下女川町 below all Onagawa

Field Investigation 3（Sendai city and south of Miyagi 仙台市と宮城南部）**29 Apr. 2011**

２ Tohoku Univ. (Sendai) 東北大学（仙台）

３ Nakano elem. school 仙台市中野小学校

４ Arahama, Sendai city 仙台市荒浜

５ Arahama sc., Sendai 仙台市荒浜小学校

６ Arahama sc., Sendai 仙台市荒浜小学校

７ Arahama sc., Sendai 仙台市荒浜小学校

Field Investigation 4 現地調査 4 （Kesen-numa, Kamaishi 気仙沼市−釜石市）**12 Nov. 2011**

1 CDB, Kesen-numa 気仙沼市中心街

2 CDB, Kesen-numa 気仙沼市中心街

3 Temporary office/shops 気仙沼仮設店舗等

4 Kamaishi Port 釜石港（船舶撤去跡）

5 Kamaishi City Hall 釜石市役所

6 City & Kamaishi Port 釜石港周辺市街地

Field Investigation 5 （Minami-sanriku etc, Miyagi　宮城県南三陸町他）**13-16 Nov. 2012**

1 Ookawa elem. Sc. 石巻市大川小学校

2 Minami-sanriku town　宮城県南三陸町

3 Minami-sanriku town, Miyagi pref. 宮城県南三陸町　2011.9

4 Suginoshita, Kesen-numa 気仙沼杉ノ下

5 Ootsuchi Town Hall　大槌町役場

Field Investigation 6（Miyako-Rikuzentakata, Iwate 岩手県宮古 - 陸前高田）**25- Aug. 2013**
(6-1) 25-26 Aug. 2013 by GRIPS　2013 年 8 月 25－26 日
政策研究大学院大学　防災・復興・危機管理プログラム被災地学習 1

１ Taro Kanko Hotel　田老観光ホテル

２ Jodogahama, Miyako　宮古市浄土ヶ浜

３ View from Miyako city hall 宮古市庁舎より

４ Ootsuchi Town Hall　大槌町役場

５ Unosumai DM Center 釜石 鵜住居防災Ｃ

６ City & Kamaishi Port 釜石港周辺市街地

(6-2) 26-27 Aug. 2013 by GRIPS　防災・復興・危機管理プログラム被災地学習２

７ Kamaishi City Hall　　釜石市役所

８ Temporary shops　釜石青葉公園商店街

９ City of Kamaishi 釜石市中心市街地

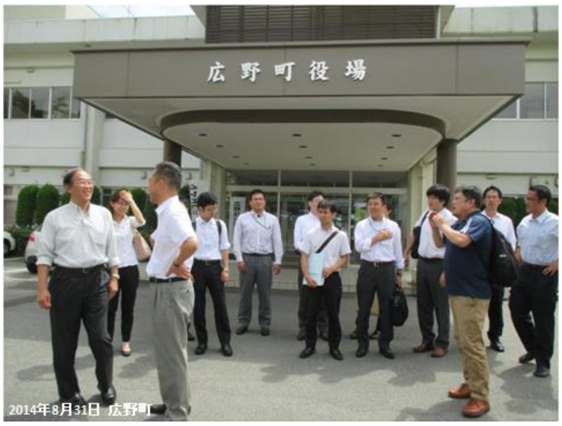
１０ City of Kamaishi 釜石市中心市街地

１１ Rikuzen-takata　　陸前高田市防集工事

１２ Rikuzen-takata　　陸前高田市一本松

Field Investigation 7 現地調査７（Fukushima coast 福島県沿岸部）**30 Aug.- 1 Sept. 2014**

１ Temp. house, Iwaki　いわき市仮設住宅



２ Hirono Town Hall　広野町役場

３ Hirono Reconst. site　広野町復興現場

４ Naraha town　楢葉町災害廃棄物置場

５ Ookuma town　大熊町

６ Fukushima power st. 大熊町福島第一原発

4. Document of Building Research Institute on Eq. and Tsunami
(独)建築研究所 東日本大震災震害及び津波被害報告概要（英文）

Tsunami Disaster of the Great East Japan Earthquake and towards its Reconstruction

和文は以下のサイト参照： http://iisee.kenken.go.jp/special2/20110311tohoku_ja.htm

（報告書） http://www.kenken.go.jp/japanese/contents/topics/20110311/

http://www.kenken.go.jp/japanese/contents/topics/20110311/0311report.html

This section is translated based on the BRI Japanese report and GRIPS has responsibility of translation.

Damage to Buildings in Inundation Areas Induced by Tsunami

1 Introduction

The purpose of this investigation is to understand an overview of buildings damaged by tsunami, to obtain basic data and information required to evaluate mechanisms for causing damage to the buildings and to contribute to tsunami load and tsunami-resistant designs for buildings such as tsunami evacuation buildings, by means of collecting building damage cases by tsunami, classifying the damage patterns for different structural categories, and making a comparison between the calculated tsunami force acting on buildings and the strength of the buildings.

The tsunami damage survey team* organized in the Joint Survey Team consists of 27 members, for voluntary investigation. The team collected national and international standards and codes concerning tsunami evacuation buildings and tsunami loads and surveyed about 100 buildings and structures in three site investigations.

2 Classification and Discussion of Damage Patterns

2.1 Reinforced concrete buildings

1) Collapse of first floor

A case where column capitals and bases on the first floor in a building were subject to bending failure and subsequently to story collapse was seen in 2-story buildings (Photo 2-1).

These buildings have column-to-beam frames. The first floor has a relatively small number of walls, but many concrete block walls are placed on the second floor. The first and second floors of the building in Photo 2-1 are used as shop and dwelling, respectively. The relevant buildings are estimated to have structural characteristics of low strength and stiffness on the first floor.

As an opening on the second floor is not large, it is assumed that the second floor suffered a large tsunami wave pressure and the shear force acting on the first floor exceeded the lateral load-bearing capacity, resulting in the collapse of the building. Story collapse of the first floor has not been observed in 3-story or higher buildings in the investigations. In 3-story buildings, in general, reinforced concrete walls are often used for the first floor. Therefore, the strength of the first floor of 3-story buildings is considered to have been larger than that of 2-story buildings.

Photo 2-1: Story collapse of a 2-story reinforced concreted building (left)
Photo 2-2: Overturning of a 3-story reinforced concrete building (right)

2) Overturning

Overturning was observed in 4-story or lower buildings. In all overturned buildings, the maximum inundation depth exceeded their height. Overturning types include building that fell sidelong (Photo 2-2) and buildings that turned upside down. Most of the overturned buildings are of mat foundation. In some overturned buildings on pile foundation, piles were pulled out.

Overturning cases were often seen in 4-story or lower buildings with relatively small size of openings. However, there were many cases where 4-story or lower buildings with large size of openings were not overturned. Consequently, the size of opening on an exterior wall is considered to have greatly affected overturning.

In some cases, there were tsunami traces at the heights of the upper end of openings on the top floor inside the buildings whose heights were exceeded by maximum inundation depths. It is considered that air has accumulated in the space between the ceiling and the upper end of openings.

Overturning is considered to occur when an overturning moment by tsunami wave force exceeds an overturning strength by a dead load of a building (considering the effect of buoyancy as required). A building, in which the distance from the upper end of an opening on each floor to a ceiling is long, may be overturned even by a slight horizontal tsunami force when buoyancy significantly acts on the building.

3) Movement and washout

Most of the overturned buildings were moved from their original positions. It is estimated that large buoyancy acted on the buildings. Moved and overturned buildings left no dragged traces on the ground. One of the buildings moved over a concrete block fence with about 2m height on an adjoining land without destroying the fence (Photo 2-3).

The building seems to have floated up by buoyancy. Some of the 2-story apartment houses with the same shape that were overturned were washed away and missing. A buoyancy and large horizontal force seem to have acted on these buildings.

Photo 2-3: A 2-story RC building that moved over the fence and overturned
Photo 2-4: A 2-story RC building that was tilted by scouring (right photo)

4) <u>Tilting by scouring</u>

When tsunami acted on a building, a strong stream was generated around the corner of the building, resulting in many large holes on the ground that were bored by scouring. In one case, a building on mat foundation fell into a hole bored by scouring (Photo 2-4).

5) <u>Fracture of wall (fracture of opening)</u>

When tsunami acts on openings in a building and openings of the opposite side of the building are smaller than the affected openings, a stream flowing from the affected openings concentrates on the opposite small openings. In one observed case related to this event, a stream generated by tsunami provided a large pressure to a reinforced concrete non-structural wall around small opposite openings. The pressure enlarged the concrete wall to the outside and fractured the wall reinforcement.

A tsunami wave force that acts on a building will be reduced if the size of opening affected by the force becomes larger. The same trend is considered to apply to an outlet surface of the stream.

A case where such wall reinforcement was fractured is often seen in wall members with single layer bar arrangement. In one damaged building (Photo 2-5), a 300 mm-thick shear wall with double layer bar arrangement and a support span of more than 10 m and without the second and third floor slabs was bent inside by tsunami wave pressure.

However, a shear wall in an area (Photo 2-5 Back of the building, right-hand side), where there is a floor on the second story and a support span is not long in the same building, was not bent.

6) <u>Debris impact</u>

Debris impact was seen in most of the non-structural members such as window and ceiling materials. The number of cases of clear damage to skeletons was not large, but in one observed case, a multi-story wall in an apartment house was probably bored by debris impact (Photo 2-6).

Photo 2-5: Out-of-plane fracture of RC shear wall without floor (left)
Photo 2-6: Wall opening generated by debris impact (right)

2.2 Steel buildings

1) <u>Movement and washout by fracture of exposed column base</u>

A typical case of building movement and washout is that a building moved and flew due to the fracture of anchor bolts and/or base plates at steel exposed column bases and the fracture of a weld between the column and the base plate (Photo 2-7). In most cases, a foundation and some column bases were left in a site, but the body of a building was moved beyond the site or missing.

Photo 2-7: Steel building overturned by fracture of column base anchor bolts

2) <u>Movement and washout by fracture of capital connection</u>

In damage cases relatively often seen a capital connection on the first or second floor in a building was fractured, then the building was moved and washed away. When a column base has a large strength like concrete encases type or embedded type, this type of fracture is considered to occur. In one case (Photo 2-8), foundation in a building, and several columns on the first floor (or up to the second floor) were left on the site, and the columns fell in the same direction.

In most cases, welds between diaphragms with lower flanges and the first-floor columns were fractured and the sections of the columns were exposed. In one building, flanges of the second-floor H-shaped beams were torn. Based on the deformation states near the column bases, it is estimated that a tensile force acted on the first-floor columns, and then the first-floor capital connections were fractured after the first floor was greatly tilted to the same extent as the inclination of the remaining columns.

Photo 2-8: First-floor columns falling in the same direction

3) <u>Overturning</u>

One case, in which a whole building including foundation is overturned, was confirmed. Most of the AAC panels of claddings were left (Photo 2-9).

Photo 2-9: Overturning of a 3-story steel building
Photo 2-10: Story collapse of first floor in a 2-story steel building

4) <u>Collapse</u>

Skeleton collapse including story collapse of the first floor was seen in a 2-story steel building (Photo 2-10). Partial collapse of a warehouse was also seen on the coast.

5) <u>Large residual deformation</u>

Slight tilting was often observed with remaining their skeletons in steel buildings. In one case (Photo 2-11), a gabled roof frame building did not collapsed despite large residual deformation.

Photo 2-11: Tilted gabled roof frame Photo 2-12: Tilted frame

6) <u>Full fracture and washout of cladding and internal finishing materials</u>

Cladding materials such as AAC panel were almost fully fractured and washed away, and then a steel frame as a skeleton was remaining. This case was often observed (Photo 2-13). It is considered that an external force that acts on the skeleton became small due to early washout of the cladding materials. In the remaining building, slight tilting of the skeleton, member deformation on the face affected by tsunami, or members locally damaged possibly by debris impact, were observed.

Photo 2-13: A remaining 3-story steel building

In another damage case, openings on the face affected by tsunami and on its opposite face, or transverse faces were severely damaged and fractured possibly due to stream runoff.

2.3 Wooden Structure

The damage type of wooden structure is considered as closely relates to the maximum tsunami depth. If the maximum tsunami depth becomes more than 4 m (= equivalent to the level of 2nd floor of a wooden house), almost of all wooden structures that have less than 2-story have not left. Typical damages are; super structure was washed away although the base and foundation was remained (Photo 2-14), or foundation was also washed away and only RC base was remained.

Photo 2-14: Remained base without upper structure

On the other hand, if the maximum tsunami depth was around 1-2 m, most of wooden buildings are remained. When the structure had damages, they were thought to be caused by the collision of floating wreckage.

Photo 2-15: Remained housed behind a remained building

If the maximum tsunami depth was between 2m and 4m, partial remainder case of wooden structure was confirmed. When a withstood building or structure existed in front of wooden structure towards the direction of tsunami wave, some of back side wooden structures were remained. This is the case that acting tsunami wave force was greatly reduced because of the remaining building.

Other remaining cases were confirmed such as the case of “Piloti form (open space at the 1st floor)” structure that tsunami forces may have been reduced because of large opening in the plan and/or the section, and the case that was remained even though the column and exterior walls of the corner was lost.

In addition, vertically mixed structure with RC and so on in the 1st floor was also confirmed to be remained in some cases. (Photo 2-16)

Photo 2-16: Case of wooden house with 1st story RC structure

4 Database for Investigated Buildings

Outer dimensions of about 100 buildings and dimensions of their skeletons were measured in the site investigation. Maximum inundation depths were measured from tsunami traces on surveyed buildings and surrounding buildings. These measurement results were integrated into a database for investigated buildings. Building name, address, building use, construction year, designation as tsunami evacuation building, structure category, number of stories, outer dimension, distance from seacoast (river), GPS position, altitude, surrounding circumstances, damage situations, etc., were included in the database. In addition, photos of investigated buildings that were taken from four directions as possible were attached to the database. Based on the database, the joint survey team estimated strengths of the buildings and tsunami loads on them, and is evaluating whether the estimated values are consistent with the damage situations.

5 Conclusion

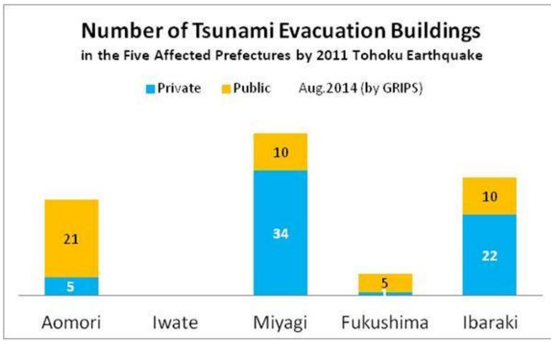
This paper classified the damage patterns for different structural categories and briefly discussed the factors that had caused various types of damage. Based on the results of the relevant investigation, we are now conducting an additional site investigation as required and collecting design documents for damaged buildings, while further evaluating the effects of building openings and buoyancy and proceeding with the elucidation of mechanisms for causing damage and the identification of tsunami loads on buildings.

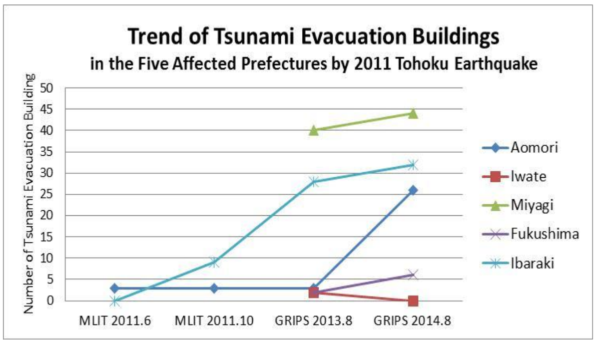
* Tsunami Damage Survey Team (The members' positions as of April 20, 2011)
NILIM (8 members): Isao Nishiyama, Akiyoshi Mukai, Ichiro Minato, Atsuo Fukai, Shuichi Takeya, Hitomitsu Kikitsu, Hiroshi Arai, and Tomohiko Sakata
BRI (19 members): Juntaro Tsuru, Nobuo Furukawa, Masanori Iiba, Shoichi Ando, Wataru Gojo, Hiroshi Fukuyama, Yasuo Okuda, Taiki Saito, Bun-ichiro Shibazaki, Koichi Morita, Hiroto Kato, Tsutomu Hirade, Takashi Hasegawa, Tadashi Ishihara, Norimitsu Ishii, Yushiro Fujii, Haruhiko Suwada, Yasuhiro Araki, and Toshikazu Kabeyasawa

Trend of Tsunami Evacuation Buildings in the Affected Regions by 2011 Great East Japan Earthquake /Tsunami

Shoichi ANDO , : Prof., National Graduate Institute for Policy Studies (GRIPS),
ando@grips.ac.jp : 7-22-1 Roppongi, Minato-ward, Tokyo, 106-8677 Japan

Before the 2011 Tohoku Earthquake (Great East Japan Earthquake), tsunami evacuation buildings were designated in the affected regions in Iwate, Miyagi and Fukushima prefectures. Most of them functioned against tsunami and saved many surrounding residents' lives. The photo 1 shows a tsunami evacuation building in Minami-sanriku town was a public hospital with five-story and although even fourth floor was inundated, many people evacuated fifth or top floor. However, municipality of Kamaishi city retracted the designation even for a remained building with eight stories. It seems that heavily affected municipalities tend to be more circumspect to designate tsunami evacuation buildings again.





On the other hand, less affected areas even in Miyagi prefecture like Tagajo city or other prefectures like Aomori and Ibaraki, municipalities in the coastal area designate many tsunami evacuation buildings recently. The author shows actual conditions and analyses the background of tsunami evacuation buildings in the affected regions.

Photo 1: (left)
Demolished
Tsunami Evacuation
Building in Minami-
Sanriku, Miyagi
June 2012 (S. Ando)

Photo 2: (right)
Tsunami Evacuation
Building remained
but retracted its
designation in Iwate
Aug. 2013 (S. Ando)

March 2015

Joint Project by
National Graduate Institute for Policy Studies (GRIPS)
and IISEE of Building Research Institute (BRI), JAPAN