# RELATIONAL ANALYSIS BETWEEN TSUNAMI AND HOUSE DAMAGE AT THE INUNDATION AREA IN IWATE, JAPAN

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The estimated tsunami height and inundation depth in March 11th, 2011 were shown and geographically analyzed. The spatial distribution of tsunami inundation and its height were visualized with GIS, and regional characteristics of representative areas were spatially examined. Considering the spatial distribution of inundation area, depth and house damage, it was separated by three groups having a similar characteristics. The zonal classification by house damage and typical inundation depth were clarified the regional features and differences.

Keywords: *Great East Japan Earthquake; Tsunami; House Damage*

## INTRODUCTION

The Great East Japan Earthquake (GEJE) occurred in March 11th 2011. The epicenter of Earthquake was 38.103 degrees north latitude and 142.860 degrees east longitude. The scale of moment magnitude reached 9.0. The maximum seismic intensity was 7 in Kurihara city of Miyagi prefecture. Tsunami caused by the Mega-Earthquake had a big impact. According to the press release of the National Police Agency, Japan in March 11th 2014, dead and missing persons by Tsunami in March 11th Earthquake and aftershock reached 18,517 in 12 prefectural and city governments. Especially in Iwate Prefecture, death and missing person was above 6,000, the number of collapsed houses for living were around 23,000 (Table 1). Iwate Prefecture defined the 24 bays and coasts considering the type of coastal topography, existence of offshore big breakwater (Figure 1). Yanagawa *et al.* (Yanagawa and Sakai 2014) organized 3 types of features (topography, propagating tsunami and suffering houses and buildings) by using observed data, and analyzed the house and building damage with some indicators. According to that results, the ratio of collapsed houses were relatively low at Kuji and Miyako, but other area's average collapse ratio was 84.9%. And, the scale of Hatori's destruction ratio (Hatori 1964) is strongly related to the magnitude of damage and number of damaged houses. Hatori's evaluated value for collapsed houses of 15 areas in 24 coastal areas were above 90%, 6 areas were between 80-90%, 3 areas were between 70-80%, and only 1 area was below 70%. It means that almost all area affected by the tsunami was devastating. However, its study was discussed only by observed point data, their results did not include the spatial characteristics of tsunami. It is supposed that the regional difference of house damages is due to diverse features. For example, ground level, distance from the shoreline, coastal geography, size of the bay, house structure type, house density, located altitude of house, tsunami wave height, wave force, wave direction and so on. In this study, the relational analysis between Tsunami and house damage including spatial conditions was carried out. In particular, the inundation depth, the most effective parameter for the house damage, had been focused on.

**Table 1. Tsunami damage in Iwate coastal 12 cities. It's data was referenced by Iwate Prefecture in October 31, 2012.**

| City/Town/Village | Death | Missing | Collapsed Houses |
|---|---|---|---|
| Hirono Town | 0 | 0 | 26 |
| Kuji City | 3 | 2 | 278 |
| Noda Village | 39 | 0 | 479 |
| Fudai Village | 0 | 1 | 0 |
| Tanohata Village | 17 | 15 | 270 |
| Iwaizumi Town | 10 | 0 | 200 |
| Miyako City | 467 | 94 | 4,098 |
| Yamada Town | 676 | 149 | 3,167 |
| Otsuchi Town | 853 | 433 | 3,717 |
| Kamaishi City | 986 | 152 | 3,655 |
| Ofunato City | 414 | 79 | 3,934 |
| Rikuzentakata City | 1,598 | 215 | 3,341 |
| Total | 5,063 | 1,140 | 23,165 |

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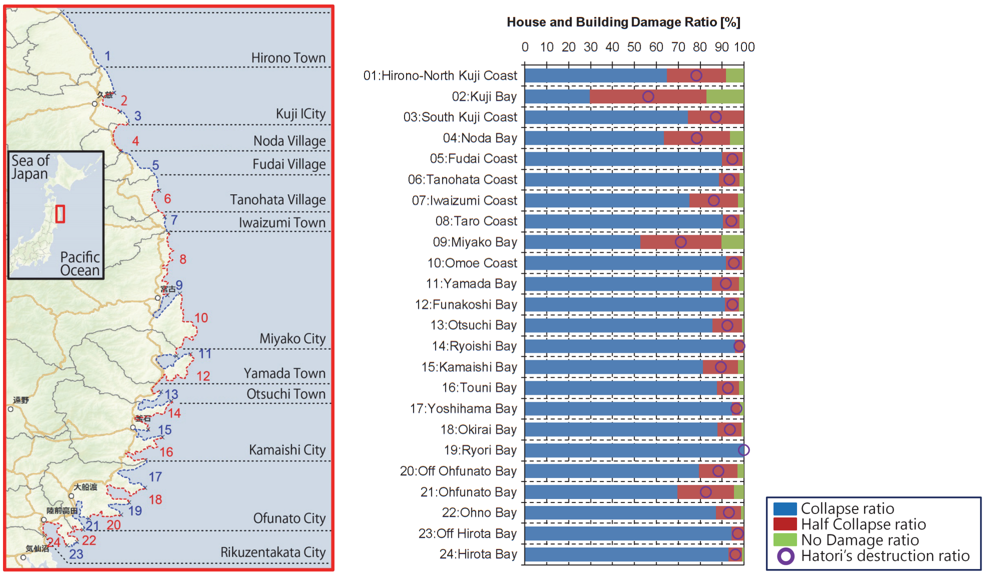



**Figure 1. House and building damage (Collapse, Half Collapse, No Damage, Hatori's destruction ratio ) suffered by 2011 Tsunami at the 24 coastal areas.**

## DATA COLLECTIONS AND METHODS

### Tsunami Numerical Model

Iwate prefecture executed the tsunami numerical simulations of the Tohoku 2011 tsunami. The wave propagation calculated from the offshore epicenter to the land based on the Non-linear Long-Wave equations, and Honma's overflow discharge formula applied to reproduce the tsunami run-up phenomena. 7 types of spatio-resolution were nested, the finest grid resolution was 10m. The calculation period in the simulation was 3 hours from the earthquake occurred. For the analysis, the maximum wave height (tsunami height in the sea from the T.P., hereinafter tsunami height), tsunami inundation height (inland tsunami height from the T.P., hereinafter inundation height) and tsunami inundation depth (inland tsunami height from the ground level, hereinafter inundation depth) was utilized. In this case, the output of these calculation data were employed. The number of finest calculation domains was 20, these are density-populated areas. Then, selected 27 regional areas were selected from the 20 calculation domains. The reproducibility of calculation was assured by the comparison between the calculation data and field observation data. Regarding the numerical model accuracy, K and κ value by Aida's method (Aida 1984) was utilized. K value shows each consistency between calculated value and observed value. Its value is 1.0 when the calculated value is identical to the observed value. When its value is in 0.8-1.2, it can be determined that the numerical model result reproduces with high accuracy. κ value means the degree of variation, so less than 1.6 is generally appropriate to use. In this study, K value was 0.97-1.21 and κ value was 1.00-1.38. Therefore, it was regarded that numerical model output had reproduced actual situation fairly, and each studies were conducted.

### Houses and Buildings in the Tsunami Inundation Area

Ministry of Land, Infrastructure, Transport and Tourism in Japan (MLIT) conducted an investigation of house and building damage by tsunami in the inundation area for widely eastern Japan. Their data set includes the spatial position of houses and buildings, structure type and type of damage. In Iwate, the number of 40,083 houses and buildings were selected. (Table 3, Figure 3) To clarify the aspect of houses and buildings, their information was classified on the structure type and damage for each area.

### Ground Level After the GEJE

Geospatial Information Authority of Japan (GSI) implemented the aerial survey in 2011-2012, aerial photographs and laser intensity direction and ranging (LiDAR) data at the seafront area has collected. As the ground level after the GEJE, the digital elevation model (DEM) data with 0.2 seconds (Approximately 5m grid) horizontal resolution has been published and utilized for this study.

### Estimation of Inundation Depth

Tsunami inundation depth was calculated by the subtraction of DEM after GEJE from the estimated maximum tsunami inundation height. These handling was held on GIS (Figure 4).

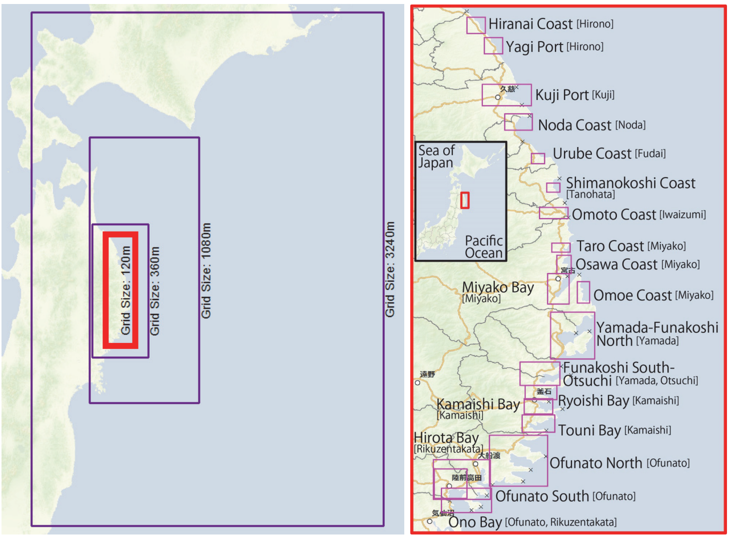



**Figure 2. Tsunami calculation domain, rectangular with caption areas are selected 20 calculation domains.**

**Table 2. Configuration of tsunami numerical model of Tohoku 2011 Tsunami.**

| Item | Setting |
|---|---|
| Calculation Area | Reference Figure 2 |
| Basic Equation and Solving Method | Based on the Non-Linear Long-Wave equation<br>Application of staggered leap-flog method<br>Honma's overflow discharge formula for tsunami run-up |
| Calculation Grid and Resolution | 3240m, 1080m, 360m and 120m without tsunami run-up<br>40m, 20m and 10m with tsunami run-up |
| Roughness Coefficient at the ground | Reference by Kotani et al. (1998)<br>Sea, River:0.025, Agricultural field:0.050, Forest field:0.030<br>Residential area: 0.040(low density), 0.060(medium density), 0.080(high density) |
| Seismic Slip Model | Fujii and Satake's slip model (ver.4.0) |
| Topography | Modified 1994 Iwate Tsunami Prediction Model or Survey data in 2011-2012 |
| Sea Surface Deformation by the Earthquake | Manshinha & Smylie's Method (1971)<br>Scale factor was calibrated by 1.05-2.90 times from the comparison between estimate value and field survey |
| Calculation Period | 3 hours from the earthquake outbreak |
| Time Resolution | 0.1-0.4 sec, dependent on the calculation area |

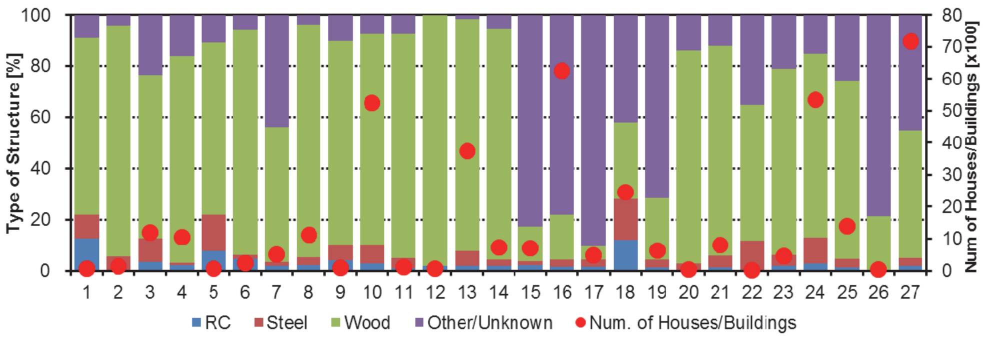



**Figure 3. Number and ratio of classified houses and buildings in each target region.**

**Table 3. Number of houses and buildings in the inundation area.**

| No. | Name | RC | Steel | Wood | Unknown/Others | Total |
|---|---|---|---|---|---|---|
| 1 | Hiranai Coast | 7 | 5 | 38 | 5 | 55 |
| 2 | Yagi Port | 0 | 7 | 112 | 5 | 124 |
| 3 | Kuji Port | 41 | 110 | 771 | 285 | 1,207 |
| 4 | Noda Coast | 22 | 9 | 853 | 171 | 1,055 |
| 5 | Urube Coast | 5 | 9 | 43 | 7 | 64 |
| 6 | Shimanokoshi Coast | 11 | 3 | 203 | 13 | 230 |
| 7 | Omoto Coast | 9 | 8 | 262 | 218 | 497 |
| 8 | Taro Coast | 25 | 33 | 1,013 | 42 | 1,113 |
| 9 | Osawa Coast | 4 | 6 | 78 | 10 | 98 |
| 10 | Miyako Bay | 154 | 376 | 4,322 | 400 | 5,252 |
| 11 | Omoe Coast | 1 | 5 | 105 | 9 | 120 |
| 12 | North Yamada | 1 | 0 | 49 | 0 | 50 |
| 13 | Yamada Bay | 74 | 216 | 3,383 | 63 | 3,736 |
| 14 | North Funakoshi | 14 | 17 | 661 | 39 | 731 |
| 15 | South Funakoshi | 16 | 10 | 95 | 582 | 703 |
| 16 | Otsuchi Bay | 104 | 160 | 1,104 | 4,878 | 6,246 |
| 17 | Ryoishi Bay | 8 | 13 | 24 | 425 | 470 |
| 18 | Kamaishi Bay | 298 | 392 | 728 | 1,031 | 2,449 |
| 19 | Touni Bay | 7 | 21 | 152 | 454 | 634 |
| 20 | Yoshihama Bay | 0 | 1 | 30 | 5 | 36 |
| 21 | Okirai Bay | 9 | 38 | 669 | 98 | 814 |
| 22 | Ryori Bay | 0 | 2 | 9 | 6 | 17 |
| 23 | Off-Ofunato Bay | 9 | 20 | 335 | 97 | 461 |
| 24 | Ofunato Bay | 154 | 533 | 3,837 | 814 | 5,338 |
| 25 | Oono Bay | 16 | 50 | 974 | 360 | 1,400 |
| 26 | Off-Hirota Bay | 0 | 0 | 6 | 22 | 28 |
| 27 | Hirota Bay | 139 | 220 | 3,558 | 3,238 | 7,155 |
| | 27 Area Total | 1,128 | 2,264 | 23,414 | 13,247 | 40,083 |

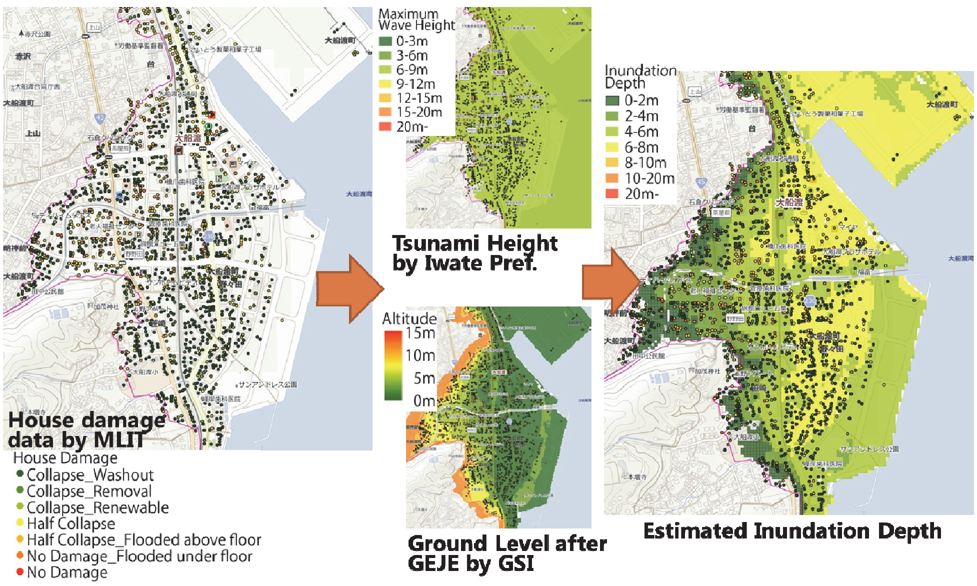



**Figure 4. Snapshot how to make inundation map. Inundation depth is equal to (tsunami height - ground level).**

## RESULTS AND DISCUSSION

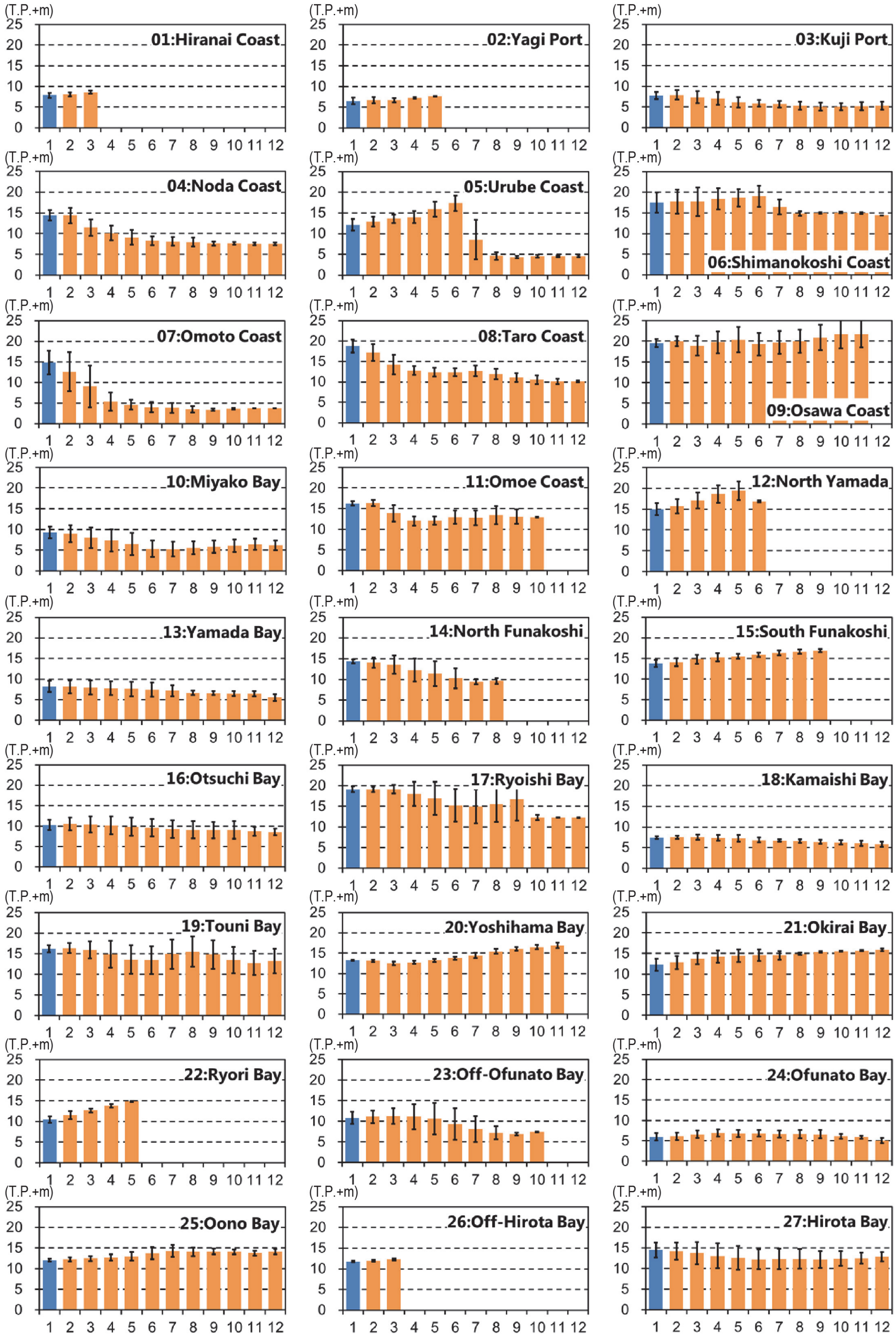
### Estimated Maximum Tsunami Height

Figure 5 shows the estimated maximum wave height (tsunami height) and inundation height at the 27 regional areas to comprehend the tsunami run-up features. Grasping the overall trend, tsunami height at Shimanokoshi Coast, Taro Coast, Osawa Coast, Omoe Coast, Ryoishi Bay and Touni Bay were relatively higher than neighboring bay area. On the other hand, enclosed coastal bays like Kuji Port, Miyako Bay, Yamada Bay, Kamaishi Bay, and Ofunato Bay were lower. It was identified that there was a tendency that nearshore tsunami height is higher in areas directly facing the Pacific Ocean, or open coastal bays. The estimated tsunami heights in high order were T.P.+19.5m in Osawa Coast, T.P.+19.1m in Ryoishi Bay, T.P.+18.8m in Taro Coast and T.P.+17.5m in Shimanokoshi Coast. Tsunami height in the northern part of Iwate coast and inner area from the offshore breakwater was qualitatively low. For example, it was T.P.+6.0m in Ofunato Bay, T.P.+6.5m in Yagi Port and T.P.+7.4m in Kamaishi Bay.

With respect to tsunami height around the shoreline, there was no difference in the sea side and land side across the shoreline in most areas, but the land side's tsunami height was slightly higher in a relatively steep slope area (Osawa Coast, North Yamada, Okirai and Ryori Bay).

At the shoreline around Urube, Omoto and Taro Coast, the great tide wall against tsunami greater than or equal to T.P.+10.0m had been installed in front of the residential area (Figure 6). The Fudai flood gate of T.P.+15.5m in Urube Coast and the Omoto flood gate of T.P.+12.7m in Omoto Coast were higher than other area's setting value. Therefore both tide wall prevented houses from fatal damage, and tsunami inundation height behind the tide wall significantly decreased. In Taro Coast, there were double tide wall with height T.P.+10m in front of the shoreline. Shoreside tide wall was broken down and tsunami water body overflowed the 2nd tide wall. Hence the inundation height at the inland area exceeded T.P.+10m. On the other hand, the lower design value facilities like in Yamada Bay, Kamaishi Bay, Ofunato Bay and Hirota Bay, tsunami height was above the wall crest considerably and destroyed, so the tide wall cannot work sufficiently.

As a comparison of tsunami run-up height between the run-up end and the shoreline, 3 conditions were classified. "inland tsunami height > shoreline tsunami height" (hereinafter "inland > shoreline" ) is Yagi Port, Osawa Coast, South Funakoshi Bay, Yoshihama Bay and Okirai Bay and so on. "inland tsunami height ≒ shoreline tsunami height" (hereinafter "inland ≒ shoreline" ) is Omoe Coast, Touni Bay and Hirota Bay. "inland tsunami height < shoreline tsunami height" (hereinafter "inland < shoreline" ) is Kuji bay, Noda Coast, Taro Coast, North Funakoshi Bay and Ryoishi Bay and so on. Condition "inland > shoreline" area consisted of narrow inland residential area and steep slope, it is thought that tsunami water mass converged and proceeded to inland, and ran up the land slope with great force. Condition "inland ≒ shoreline" area consisted of comparatively large and flat area than above condition. Tsunami water mass overflows the coastal protection facilities, and were estimated that tsunami proceeded to inland at a speed that only depends on the inundation depth. Almost all residential area except for the steep slope area were flooded. Condition "inland < shoreline" area was geographically same condition as "inland ≒ shoreline". Tsunami overflow process over the tide wall and tsunami run-up speed was estimated almost same condition, but flooded area wasn't cover the whole residential area. It means that tide wall exerted the effect of tsunami defense to some extent, and tsunami run-up didn't reach to the end of residential area. In particular, tide walls in Urube and Omoto coast were not fully-destroyed, maximum tsunami height was drastically decreased at behind the tide wall.




Horizontal Axis

1: Sea:100m - Coastline
2: Coastline - Land 100m
3: Land 100m - Land 200m
4: Land 200m - Land 300m
5: Land 300m - Land 400m
6: Land 400m - Land 500m
7: Land 500m - Land 600m
8: Land 600m - Land 700m
9: Land 700m - Land 800m
10: Land 800m - Land 900m
11: Land 900m - Land 1000m
12: Land 1000m - Land 2000m

**Figure 5. Estimated average maximum tsunami height and inundation depth. Vertical axis is based on Tokyo Peil (T.P.), the error bar is standard deviation. Horizontal axis is the distance of sea-land direction.**

**Figure 6. Snapshots of T.P.+15.5m Fudai flood gate (upper left), T.P.+12.7m Omoto flood gate (upper right), and T.P.+10m Tide Wall in Taro Coast (lower left is shoreside wall, lower right is 2nd wall ). Each pictures were taken in 2012.**

**Distribution of Tsunami Inundation and House Damage**

In order to comprehend the spatial characteristics visually, estimated maximum tsunami inundation area, inundation depth, house distribution, house density and each house damage were shown and geographically analyzed. In this part, 5 regional representative places of Iwate coastal area were introduced in Figure 7-11. House density is the number of houses in 300m square area grid. The lateral bar chart is the ratio of inundation area with depth divided into 1m each. Estimated inundation depth means the height of water column from the ground. Purple line is the observed tsunami run-up border line by aerial survey. In this study, the house damage was classified mainly 3 types (Collapse, Half Collapse and No Damage) from the 7 types (Washout, Removal, Collapse with Renewable, Half Collapse, Flooded above floor, Flooded under floor and No Damage) and discussed.

**Kuji Port (Kuji city)**

The central city area and port of Kuji are located at the inner part of Kuji Bay, and connected to the Pacific Ocean. At 5km off from the shoreline, the big offshore breakwater is planned and under construction for completion of year 2028. Along the shoreline, there were harbor facilities such as the seaborne business office and resting place of stevedore, so residential houses were not existing. There was T.P.+7.3-8.0m height tide wall in red line between coastal area and residential area, the inundation depth at the residential area was lower than that of shore, and less than 2m depth has reached 53% of the inundation area. For the houses and buildings, the ratio of collapsed houses was higher around the shore. With moving to the inland area from the shoreline, the ratio of collapsed houses decreased and half collapse & no damage ratio were increasing. Collapse ratio was 30.9%. Half collapse and no damage ratio was each 52.4% and 16.7 %.

**Miyako Bay (Miyako city)**

The central city area and port of Miyako are located at the middle area between the baymouth and inner part of Miyako bay. At the southern part of Hei River, T.P.+8.5m tide wall had been installed at the back of port facilities along the shoreline, so the inundation depth of residential area was almost below 2m as same condition as the case of Kuji. On the other hand at the northern part of Hei River, the securement of residential area was very narrow, and tide wall was not constructed. Therefore the inundation depth of this tsunami was reached 6-10m. At the inner part of Hei River, the inundation depth was higher in the vicinity of waterfront. Distribution of house damage was consisting roughly 2 regional features. almost all houses were totally collapsed at the north area of Hei River. The ratio of collapsed houses at the inner and southern part were low by the tide wall protection, many houses were avoided serious damage. Collapse ratio was 53.2%. Half collapse and no damage ratio was each 37.3% and 9.5%.

**Kamaishi Bay (Kamaishi city)**

Central city area is located at the inner part of inland Kamaishi Bay, and connected to the Kamaishi Offshore Breakwater and the Pacific Ocean. Many factories and industrial plants were present near shoreline, most of their buildings were RC or Steel structure. The biggest offshore breakwater in the world that was installed to the maximum water depth of 63m was damaged and destroyed by this tsunami. The restoration work is ongoing now. Along the shoreline, T.P.+4.0m tide wall had been constructed. Backward area’s inundation depth was 2-8m. The inundation area with 2-3m depth was largest and accounted for 21.5%. 5-6m depth area was second largest and 19.3%, 6-7m depth area was third largest and 13.0%. In comparison with the Kuji and Miyako, the dominant inundation depth of Kamaishi was deeper than other 2 areas. Regarding the house damage, the spatial distribution of damaged houses were as same tendency as central area of Kuji. The half collapsed houses around the industrial area were robust building like industrial plants, commercial buildings, seafood processing place. Many RC or Steel structure buildings were remaining with half collapse. Collapse ratio was 83.7%, half collapse and no damage ratio was each 14.5% and 1.8%.

**Ofunato Bay (Ofunato city)**

The residential areas are scattered along the shoreline in the whole Ofunato Bay. In particular, houses high density area was located in the northern to north-west part of the bay. The offshore breakwater was installed at the mouth of the bay, and connected to the Pacific Ocean. At the inner bay, the tide walls of T.P.+3.0-3.5m were constructed along the shoreline, but tsunami was inundated widely and reached 8m at maximum. The inundation area with 4-5m depth was largest and its ratio was 21.9%. Estimated inundation depth didn’t exceed 8m in this area. As a general trend, house damages were totally collapsed around the shoreline, but half collapsed or no damaged houses were dotted in the collapsed house area. Or collapsed houses were dotted in the half collapse and no damage dominated area of the northwest. This means it was caused the each houses structure, houses distribution, house density and tsunami proof strength were intricately affected. Collapse ratio was 70%. Half collapse and no damage ratio was each 25.3% and 3.7%.

**Hirota Bay (Rikuzentakata city)**

Central city area is located at the inner part of Hirota Bay, and southern sea area is connected to the Pacific Ocean. The tide walls were installed by T.P.+5.5-6.5m along the shoreline. Figure 11 shows that almost all tsunami inundation area was colored in orange, and inundation depth was estimated approximately 10m. Only a small area corresponding to the end of the low-lying, inundation depth was decreasing from the 10m. Areas where inundation depth was greater than 10m was 32.7% of the inundation area. Since area of inundation depth of 9-10m was 15.3%, the region above 9m was reached about half of the inundated area. Compare to the other regional areas, the inundation depth in Rikuzentakata was bigger. Even though residential areas were located behind tide prevention facilities and high density pine-covered area, almost all houses and buildings were collapsed. Especially, almost all houses of inland distance 1.5km from the shoreline had been completely destroyed. Collapse ratio was 95.2%. Half collapse and no damage ratio was each 2.6% and 0.2%.

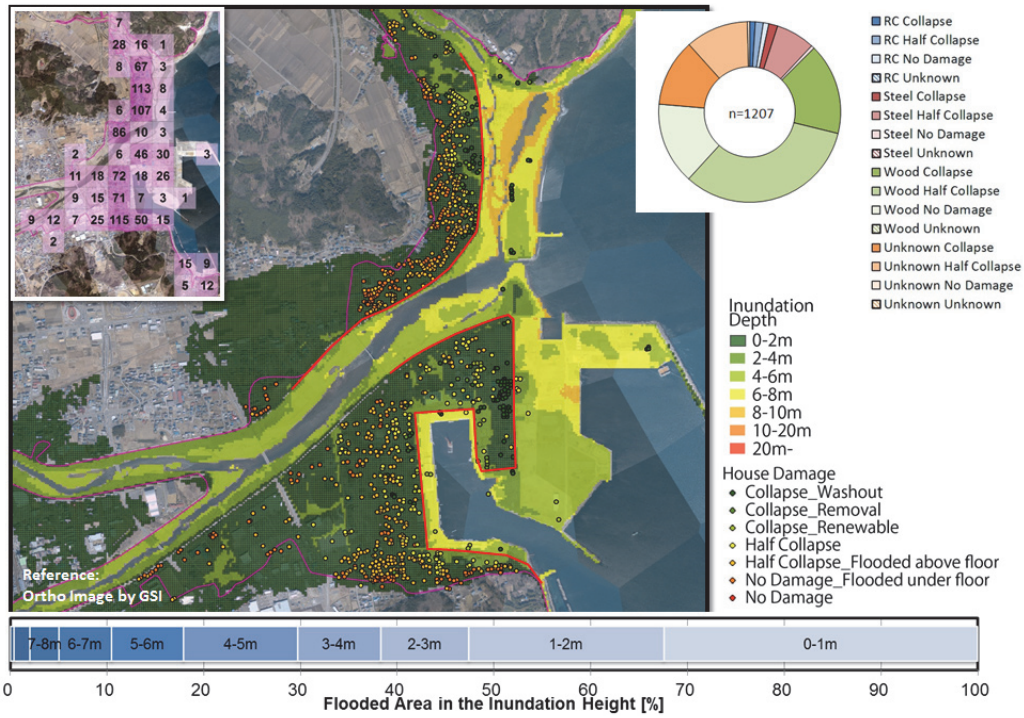



**Figure 7. Tsunami inundation & house damage in central Kuji. Colored circle in major figure is the house damage. Colored rectangular is the inundation depth. Red line is coastal protection. Pie chart is the breakdown of house structure. Purple colored square box with number is the density of houses in 300m square area grid.**

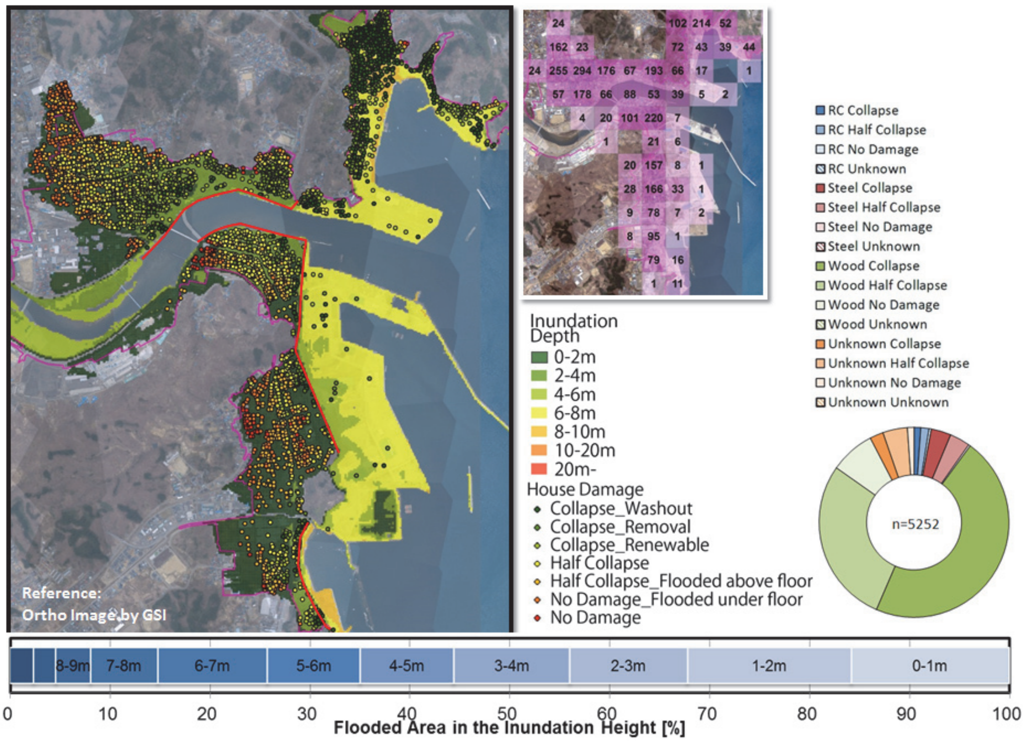



**Figure 8. Tsunami inundation & house damage in central Miyako. Colored circle in major figure is the house damage. Colored rectangular is the inundation depth. Red line is coastal protection. Pie chart is the breakdown of house structure. Purple colored square box with number is the density of houses in 300m square area grid.**

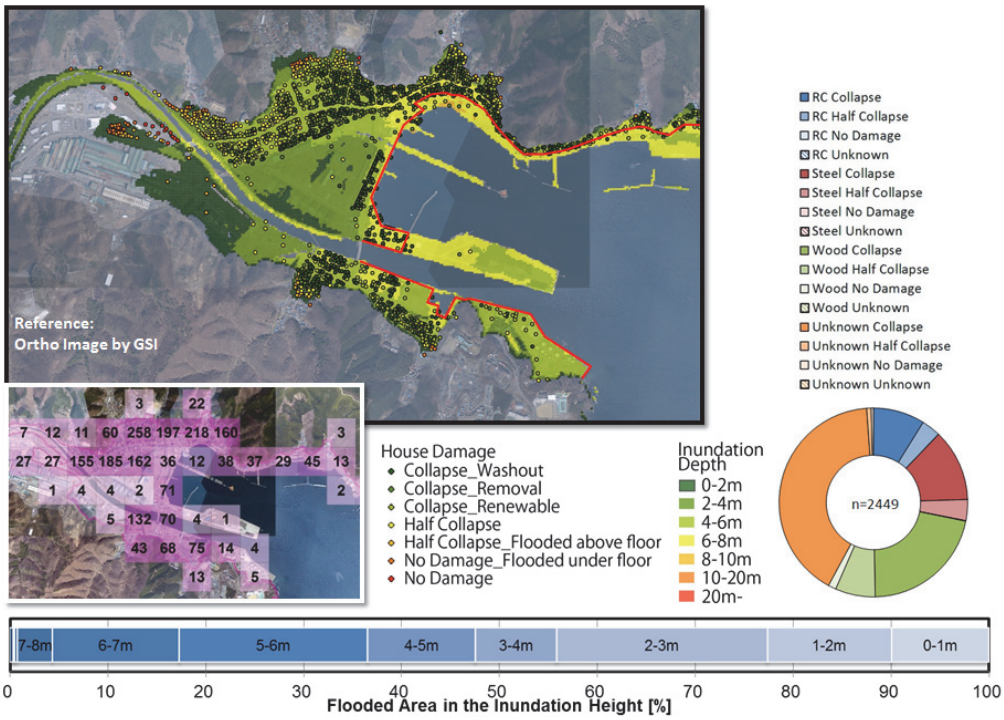



**Figure 9. Tsunami inundation & house damage in central Kamaishi. Colored circle in major figure is the house damage. Colored rectangular is the inundation depth. Red line is coastal protection. Pie chart is the breakdown of house structure. Purple colored square box with number is the density of houses in 300m square area grid.**

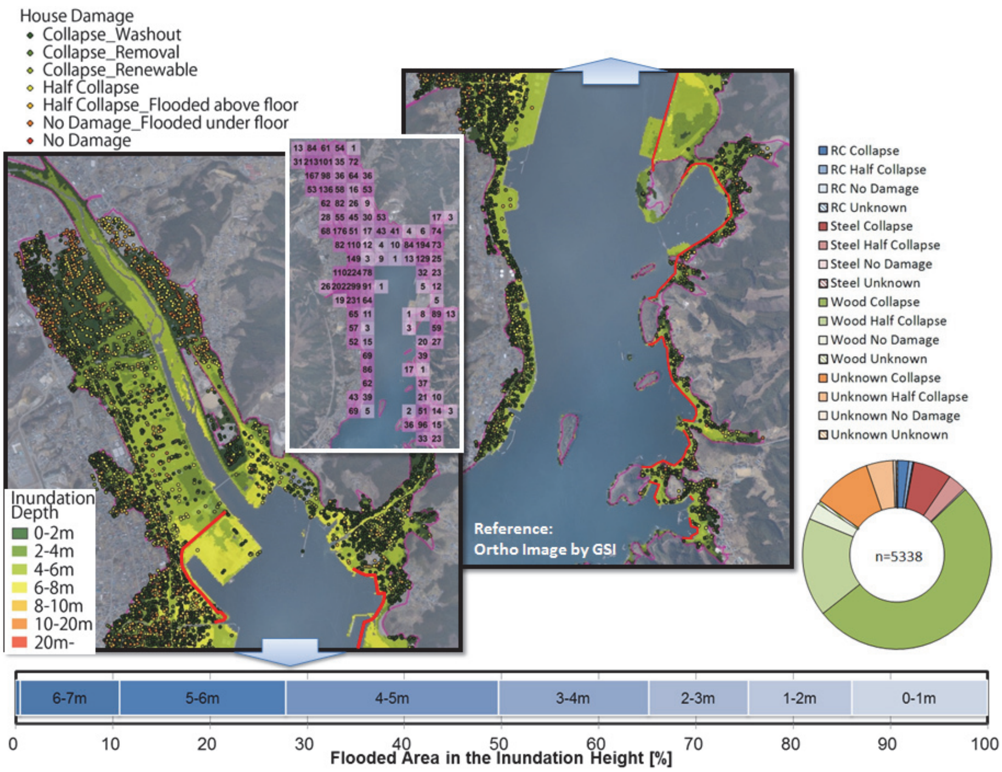



**Figure 10. Tsunami inundation & house damage in central Ofunato. Colored circle in major figure is the house damage. Colored rectangular is the inundation depth. Red line is coastal protection. Pie chart is the breakdown of house structure. Purple colored square box with number is the density of houses in 300m square area grid.**

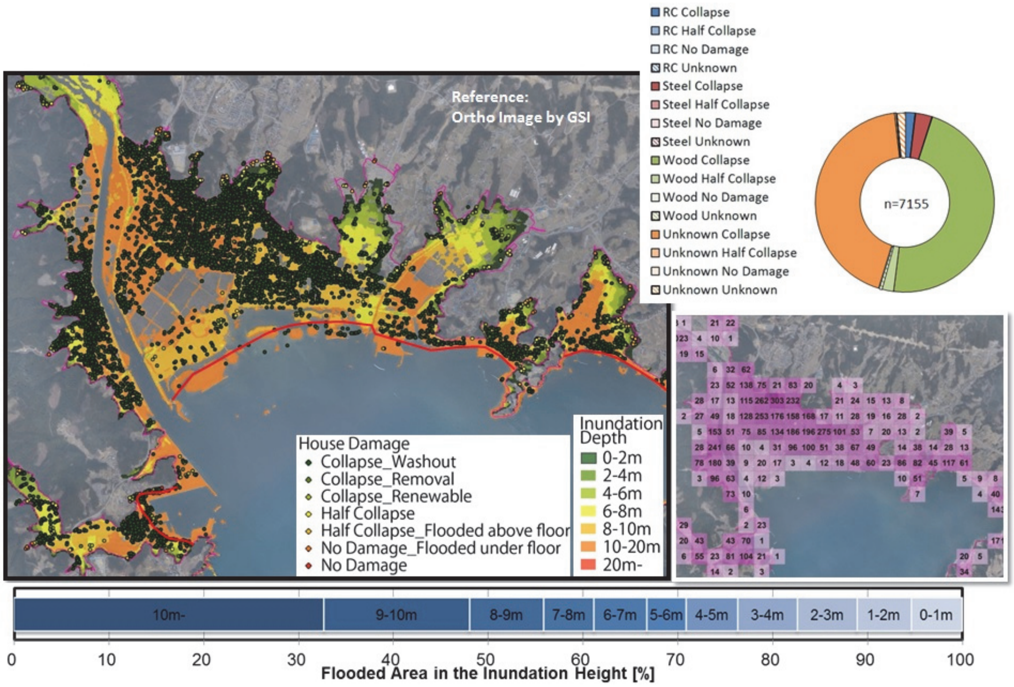



**Figure 11. Tsunami inundation & house damage in central Rikuzentakata. Colored circle in major figure is the house damage. Colored rectangular is the inundation depth. Red line is coastal protection. Pie chart is the breakdown of house structure. Purple colored square box with number is the density of houses in 300m square area grid.**

### Relation Between Inundation Depth and House Damage

In order to more concrete tendency between tsunami inundation and houses damage, the segmentalized inundation depth per 1m and the damage on each structure type were arranged (Figure 12). In each area - each structure, the tendency, with the increasing of inundation depth, the collapse ratio increasing, was clear. In Kuji, Miyako and Kamaishi's wood houses, collapsed and half collapsed houses were significantly increasing and reached around 100% more than 2m depth. For RC or Steel houses, same damage pattern appears, but RC seems to be more robust than steel. However the precise relationship between inundation depth and damage level was not found out. As for the reason, the lack of sufficient samples, variety of the structure, a number of story can be possible.

### Categorization of Tsunami Characteristics and Houses Damage in Iwate 27 Regional Areas

Considering the spatial distribution of inundation area, depth and house damage at 27 regional areas, it was separated by three groups having a similar characteristics. And then, in order to clarify the characteristics of the tsunami damage in multiple regions, the zonal classification by house damage and typical inundation depth were exerted in Table 4 and Figure 13.

### Group-1 (11 areas)

Yagi Port, Kuji Port, Noda Coast, Urube Coast, Omoto Coast, Osawa Coast, Miyako Bay, Yamada Bay, Otsuchi Bay, Kamaishi Bay and Touni Bay. Nearshore tsunami height and inundation depth at the shoreline tended to be higher than that of run-up end. Typical inundation depth was lower than other groups. The inland inundation area did not reached the end of residential area. Houses around the shoreline was totally collapsed, with moving to the inland, collapse ratio was decreasing. The dominated houses structure was wood. Steel or RC structure houses almost didn't exist in the wood dense zone. Collapse ratio was relatively lower than that of other area.

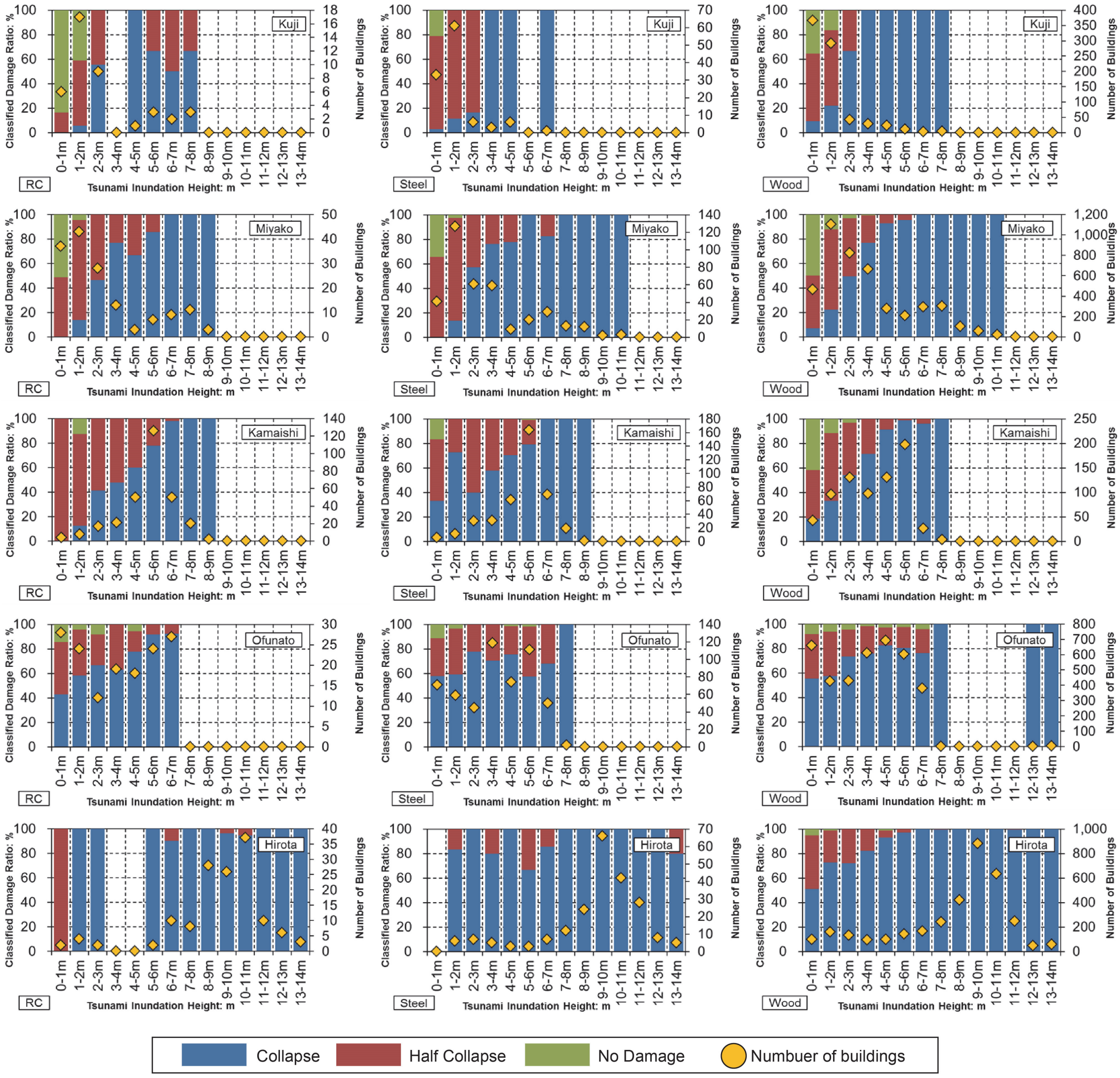



**Figure 12. The number of buildings, and the ratio of house and building damage (Collapse, Half Collapse, No Damage) by tsunami in each inundation depth.**

## Group-2 (5 areas)

Hiranai Coast, Okirai Bay, Off-Ofunato Bay, Ofunato Bay and Oono Bay. Nearshore tsunami height tended to be equal to the tsunami height at the shoreline. The inundation depth at the shore was almost same as that of run-up end. Spatial pattern of houses damage were obviously different from Group-1. Half collapsed or no damaged houses were dotted in the collapsed houses area. There were some rubust RC/Steel buildings, multistory buildings in regions where wooden houses were concentrated. Or, Collapsed houses were dotted in no damaged houses area.

## Group-3 (11 areas)

Shimanokoshi Coast, Taro Coast, Omoe Coast, North Yamada Bay, North Funakoshi Bay, South Funakoshi Bay, Ryoishi Bay, Yoshihama Bay, Ryori Bay, Off-Hirota Bay and Hirota Bay. The inundation depth at run-up end tended to be almost same as the shoreline or higher. Typical inundation depth was tend to higher than that of other group's areas. Therefore, regardless of the variety of residential structure and its density, almost all houses were collapsed and devastating.

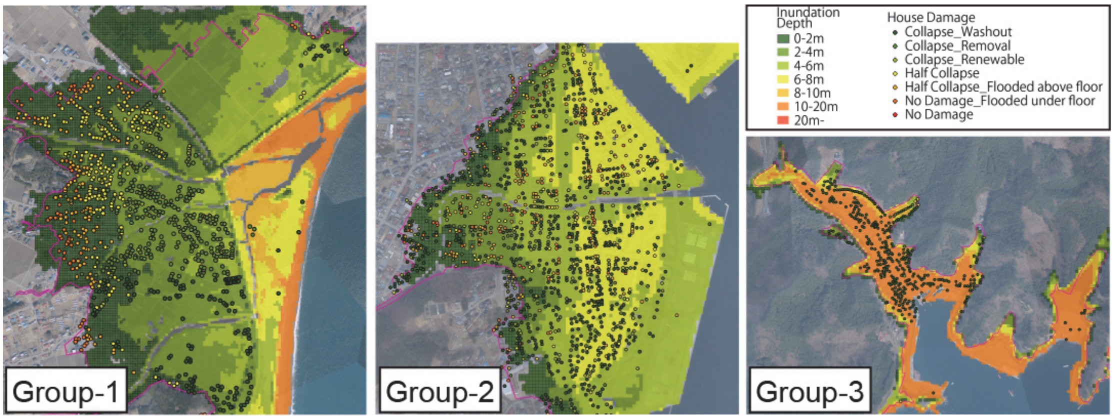



**Figure 13. Examples of spatial distribution of inundation area, inundation depth and house damage of each group.**

**Table 4. Classification by tsunami height, inundation depth and house damage characteristics.**

| Group | Tsunami height | Inundation depth | House Damage in the Area |
|---|---|---|---|
| 1 | Sea >≒ Shore | Shore >≒ Inland | Relatively low damage, Collapse houses exist around the shore, the extent of damage come down toward to the inland area. |
| 2 | Sea ≒Shore | Shore ≒< Inland | House damage is between Group-1 and Group-3. Half collapsed or no damaged houses are dotted in the collapsed houses area. |
| 3 | Sea ≒< Shore | Shore ≒< Inland | Relatively high damage, Almost all houses collapse from the shore to the inland area. |

Finally, the regional characteristics of typical inundation and house damage in 27 regional areas were organized by the point diagram (Figure 14). Vertical axis is the totally collapse ratio in each area. Horizontal axis is the typical inundation depth. Also, 3 types of group were colored in blue-green-red. In case the inundation depth is less than 2m, damage is "graded destruction type". Its type becomes higher damage at shoreline and lower damage at inland area. When the inundation depth is more than 2m, destruction type was mixed "graded destruction type" and "scattered destruction type". When the inundation depth was increasing and significantly more than the tide wall height, destruction type was "totally destruction type". From this figure, the regional features and differences in Iwate 27 regional areas were clarified.

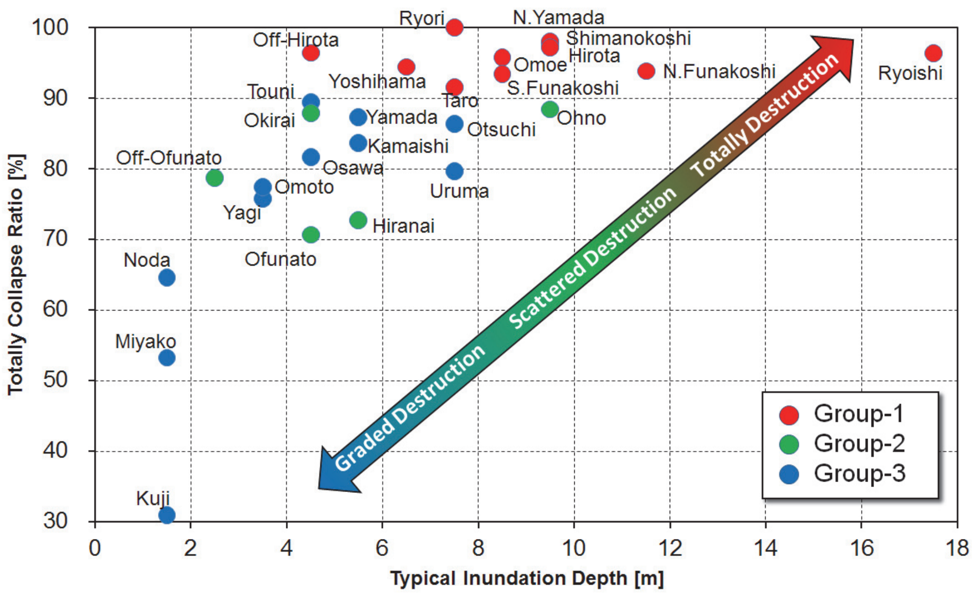



**Figure 14. Regional characteristics of inundation and house damage in Iwate 27 regional areas.**

## CONCLUSION

Through a series of this study, Tohoku 2011 tsunami characteristics and relation between inundation depth and house damage for Iwate regional areas were examined and analyzed. The following results were obtained.

1. The estimated tsunami height and inundation depth were shown and geographically analyzed in the 27 regional areas in Iwate coast.
2. The spatial distribution of tsunami inundation and its height were visualized with GIS, and regional characteristics of representative areas were spatially examined.
3. Considering the spatial distribution of inundation area, depth and house damage at each areas, it was separated by three groups having a similar characteristics. And then, in order to clarify the characteristics of the tsunami damage in multiple regions, the zonal classification by house damage and typical inundation depth were executed. In consequence, it clarified the regional features and differences.

In this study, the relationship between tsunami characteristics and house damage were qualitatively examined in each region. In order to clarify the relationship more in detail, more small-scale investigation considering tsunami inundation depth, tsunami speed, detailed coastal geography, building distribution, etc. will be preferable.

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