Regional Differences in Miyagi Prefecture Road Recovery Following the 2011 Tohoku Earthquake

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***Abstract*—We evaluate regional differences in road recovery in Miyagi Prefecture following the 2011 Tohoku Earthquake. We divided Miyagi Prefecture into three areas, i.e., Inland, Northern Coastal, and Southern Coastal areas. According to the results of our study, we conclude that the recovery conditions of regional roads in different areas of Miyagi Prefecture following the 2011 Tohoku Earthquake differed. In the Northern Coastal area, 80% of the road distance was usable by April 15, 2011 and 90% was usable by May 27, 2011. In the Southern Coastal area, 80% of the road distance was usable by March 31, 2011 and 90% was usable by April 8, 2011. Recovery in the Southern Coastal area was much faster compared to that in the Northern Coastal area. We assume that this is due to the shape of the coastlines. The coastlines in the Northern coastal area are primarily rias. The coastlines in the Southern coastal area are mostly sandy. Furthermore, we have concluded that the recovery conditions of the regional roads following the 2011 Tohoku Earthquake in the Northern Coastal area of Miyagi Prefecture were similar to those in the Southern Coastal area of Iwate Prefecture. In the disaster regions, similar recovery conditions were found according to geographic positions and features.**

***Index Terms*—2011 Tohoku Earthquake; G-BOOK telematics data; vehicle-tracking map; Iwate Prefecture; big data analysis**

I. Introduction

A. The 2011 Tohoku Earthquake

The 2011 Tohoku Earthquake [Fig.1] struck the north-eastern coast of Japan on March 11, 2011. Subsequently, the region was severely affected by the tsunami. Following these natural disasters, the electricity, water, and gas supplies were shut down in both coastal and inland areas[1], [2], [3]. Furthermore, the road travel was disrupted in many parts of the region.

B. Purpose

The primary purpose of our study was to evaluate the regional differences in road recovery in Miyagi Prefecture following the 2011 Tohoku Earthquake. Therefore, based on geographic position and features, we divided Miyagi Prefecture into Inland, Northern Coastal, and Southern Coastal areas. During the disaster, these areas were affected differently. For example, due to differences in coastal features, the tsunami struck the Northern Coastal area more heavily than the Southern Coastal area. Therefore, we assumed that there were specific differences among the three studied regions during the road recovery process following the disaster.

The secondary purpose of our study was to compare the regional differences with regard to road recovery in Miyagi Prefecture, the target of this study, compared to road recovery in Iwate Prefecture, which was evaluated in our previous study [3].

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II. Our previous studies

A. Previous study 1

Our previous study 1 [1] was focused on the use of the main roads in the Southern Coastal area of Iwate Prefecture. The usable distances of the main roads following the 2011 Tohoku Earthquake have been calculated from the G-BOOK telematics data [4].

The main findings of this study are as follows:

1) The usable distance of the roads in a weekly period has continuously increased from March 18 to April 7, 2011, but it has fluctuated thereafter.

2) Defining the cumulative usable distance up to September 30, 2011 as 100%, it has been determined that 80% of the road distance has been usable by April 7, 2011 and 90% by April 29, 2011.

3) The use of the main road in the coastal area of Iwate Prefecture has been completely recovered by April 29, 2011.

B. Previous study 2

Our previous study 2 [2] was focused on the use of the main roads not only in the Southern but also in the Northern Coastal area of Iwate Prefecture.

The cumulative usable road distance ratio of the main roads has been precisely calculated for each city using the free and open source geographical information system software QGIS. The main findings in this study [2] are listed below.

(1) The change in the cumulative usable road distance ratio during the research period differed from one city to the next.

(2) The ratio increases in the usable distances of Kuji, Iwaizumi, and Noda were extremely delayed.

In our study, we were able to determine related roads by analyzing the maps generated by the QGIS software. For Kuji and Iwaizumi, the road whose recovery was significantly delayed is the Iwate Prefectural Road number 7 (Kuji-Iwaizumi line). For Noda, the road whose recovery was significantly delayed is the Iwate Prefectural Road number 273 (Akka-Tamagawa line).

(3) In our previous study 1 [1], we determined that the use of the main road in the Southern Coastal area of Iwate Prefecture was completely recovered by April 29, 2011.

However, in this study, when we have precisely observed the change in the usable road distance ratio during the research period for each city, the ratio increase in the usable road distance of Kamaishi has been delayed compared with other Southern Coastal cities.

For Kamaishi City, the road whose recovery was significantly delayed is the Iwate Prefectural Road number 249 (Sakuratoge-Heita line).

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C. Previous study 3

In our previous study [3], we calculated the regional differences for road recovery in Iwate Prefecture following the 2011 Tohoku Earthquake. We divided Iwate Prefecture into four areas, i.e., Northern Inland, Southern Inland, Northern Coastal, and Southern Coastal areas. The main results of the previous study are as follows.

First, we determined that, for Northern and Southern Inland areas, 80% of the road distance was usable by April 15, 2011 and 90% by May 27, 2011, which indicates that the recovery speed in these areas was slightly slower than that in the Southern Coastal area.

Second, we found that, for the Northern Coastal area, 80% of the road distance was usable by April 29, 2011 and 90% by June 24, 2011, which implies that the recovery speed in the Northern Coastal area was significantly slower than that in the Southern Coastal area.

Hence, we concluded that these findings are related to the fact that road recovery efforts were more focused on regions heavily affected by the earthquake and tsunami.

III. Telematics Data and Vehicle-Tracking Map

Telematics is a general term encompassing telecommunications and informatics. A telematics service provides various personalized information for users, especially for drivers of automobiles. G-BOOK is a telematics service provided by Toyota Motor Corporation.

To calculate the usable distance of the main roads, we applied the vehicle tracking map originally created by Hada et al. [5] after the 2007 Niigataken Chuetsu-oki earthquake.

That vehicle tracking map was based on telematics data provided by Honda Motor Company. Similarly, in our study, we used the vehicle tracking map based on telematics data provided by Toyota's G-BOOK system [Figs. 2].

Registered members of G-BOOK can access telematics services to acquire GPS data for car navigation systems and interactive driving data, such as traffic jam points, road closures, and weather reports.

Such comprehensive data acquisition is possible because the telematics system server receives accurate location data (geographic coordinates) from its registered members.

Telematics services are extremely useful to drivers. Because the accurate driving routes of registered users remain in the system server, they are accessible to traffic researchers in various fields.

IV. Research Methods

A. Research area

The current study was focused on the entire area of Miyagi Prefecture (i.e., the Inland, Southern Coastal, and Northern Coastal areas) [Fig.3].

B. Research materials

In our current study, we have used the vehicle tracking maps built from the G-BOOK telematics data that is available on the Internet on March 18, 2011 following the 2011 Tohoku Earthquake [4].

The data used in this study have been collected between March 18 and September 30, 2011 (i.e., approximately six months following the 2011 Tohoku Earthquake).

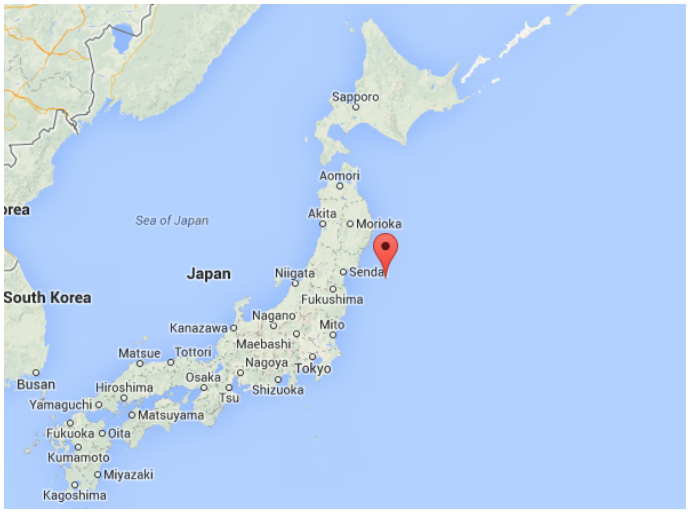

Fig. 1. Center of the 2011 Tohoku Earthquake, March 11, 2011 (https://www.google.co.jp/maps/)

C. System

Hardware:

The computations have been performed on a standard PC laptop with a Core i5-4200U CPU (1.6 GHz) and 4 GB memory (SONY VAIO PRO 11).

Software:

The software QGIS version 2.6.1 (the latest version available) [8] and LibreOffice Calc 4.2.7 spreadsheet software (the most stable version available) [9] running on the Windows 7 Professional operating system have been used in this study. It is well-known that QGIS is one of the most popular geographic information systems used worldwide.

Prior to the abovementioned applications for geographical data processing, we have used the ogr2ogr software [10] on the Linux operating system along with Vine Linux 4.2 [11], which is a Linux distribution developed by a Japanese Linux community.

Note that QGIS, LibreOffice Calc, ogr2ogr, and Vine Linux are open source softwares freely available on the Internet.

D. Data Processing

1) The vehicle tracking maps constructed from the G-BOOK telematics data have been provided in the Google map KMZ format. For our analysis, we have first converted the KMZ files to SHP files (i.e., shape-files), which are compatible with ArcGIS using the ogr2ogr software.

2) Next, the data coordinates have been converted from the terrestrial latitude and longitude to the x and y coordinates in a rectangular coordinate system.

3) To reduce the computation time, the data file has been clipped to small files containing only the research area.

4) After merging daily data into weekly data and removing duplicate data, we have been able to calculate the exact usable road distance available for a given week.

In this context, a usable road is one on which at least one vehicle has been probed during the observation period.

The purpose of converting the daily data to weekly data was to smooth the daily fluctuations in the traffic flows.

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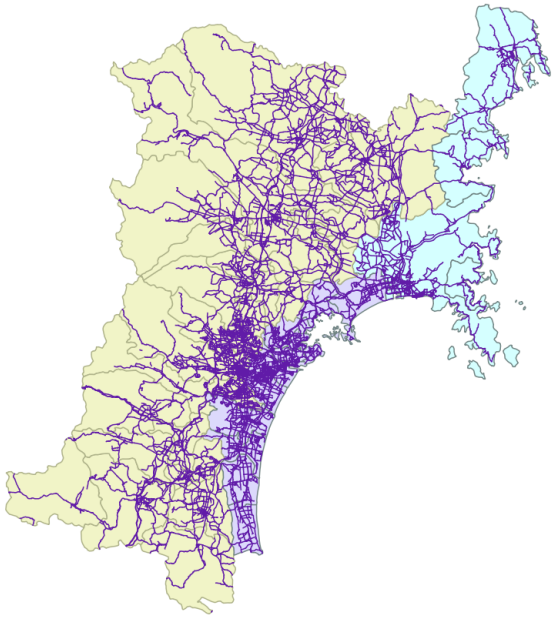

Fig. 2. Vehicle tracking map of Miyagi Prefecture

Fig. 3. Miyagi Prefecture divided into Inland, Northern Coastal, and Southern Coastal areas. The perimeter of a city is shown by a gray polygon.

5) Next, we have calculated the proportion of the cumulative distance up to the specified date. Note that the cumulative distance up to September 30, 2011 was considered 100%.

V. Results

A. Regional road recovery differences

Defining the cumulative usable distance up to September 30, 2011 as 100%, the percentages of usable road distances are given in Table.II. In Table.II, the upper lines indicate the cumulative usable road distances (in meters), and the lower lines represent the ratio of cumulative usable road distance.

1) Inland area

It was determined that 80% of the road distance was usable by April 7, 2011 and 90% was usable by April 29, 2011. The recovery speed in Inland area was slightly slower than that in the Northern Coastal area.

2) Northern Coastal area

It was determined that 80% of the road distance was usable by April 15, 2011 and 90% was usable by May 27, 2011.

3) Southern Coastal area

It was determined that 80% of the road distance was usable by March 31, 2011 and 90% by April 8, 2011. Recovery rates in the Southern Coastal area were significantly higher compared to the Northern Coastal area.

B. Cities where road recovery was delayed significantly

1) Inland area [Fig.4]

The usable road distance ratio increases for Kami, Shichigashuku, Shikama, Marumori, and Zao towns were delayed significantly compared to those for other municipalities in the Miyagi Prefecture Inland area. We were able to identify related roads by analyzing maps generated using QGIS software.

For Kami Town, the roads whose recovery was significantly delayed are Miyagi Prefectural Road number 226 (Iwadeyama-Miyazaki line) and the road that runs between National Route 347 and Ishikawa Farm.

For Shichigashuku Town, the roads whose recovery was significantly delayed are Miyagi Prefectural Road number 13 (Kaminoyama-Shichigashuku line) and Miyagi Prefectural Road number 51 (the Minamizao-Shichigashuku line).

For Shikama Town, the roads whose recovery was significantly delayed are the road between Shin-Kitsupushi and Miyagi Prefectural Road number 156, two roads between Miyagi Prefectural Road number 156 and Takane, and the road that connects Miyagi Prefectural Road number 156, Nishihara, and Ohara Farm.

For Marumori Town, the roads whose recovery was significantly delayed are as follows.

-Miyagi Prefectural Road number 45 (Marumori-Ryozen line; near Hippo)

-Miyagi Prefectural Road number 228 (Soma-Ouchi line; near Aoba Hot Spring)

-The road between Miyagi Prefectural Road number 12 and Nenashifuji

-the road between Miyagi Prefectural Road number 12 and Magatake-Goanji

2) Northern Coastal area [Fig.5]

The ratio increases in the usable distance for Minami-Sanriku Town and Kesen-numa City were delayed significantly compared to those for other municipalities in the Miyagi Prefecture Coastal area. We were able to determine related roads by analyzing maps generated using QGIS software.

For Minami-Sanriku Town, the roads whose recovery was significantly delayed are as follows.

-Miyagi Prefectural Road number 225 (Tomarizaki-hanto line)

-The road to Kesenma-Oshima Jinjya (Shrine) from Miyagi Prefectural Road number 236 (Haraikawa-Machimukai line)

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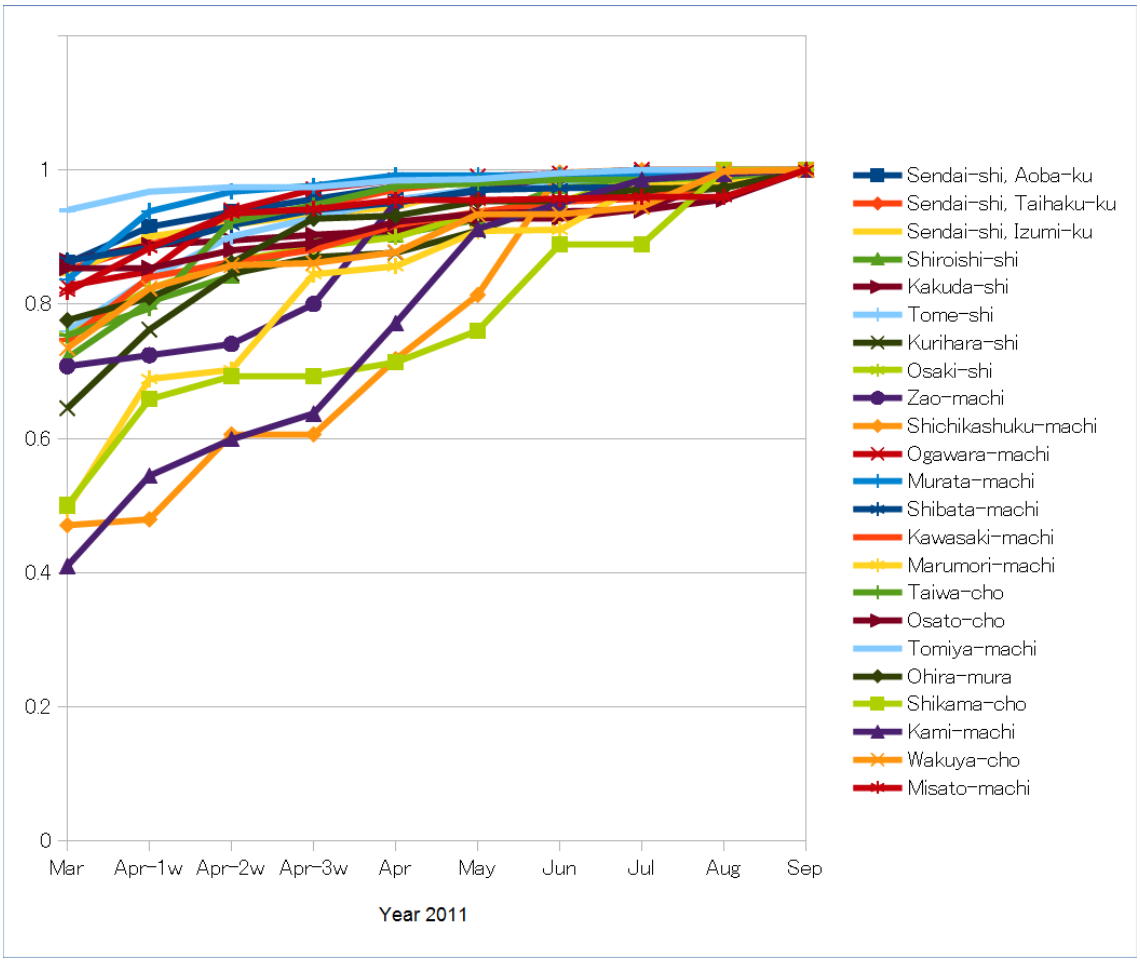

Fig. 4. Cumulative usable road distance ratio for the Inland area. The vertical scale displays the cumulative distance proportion of the usable roads (relative to the cumulative distance on September 30, 2011) for each date.

TABLE I
REGIONAL DIFFERENCES FOR ROAD RECOVERY IN MIYAGI PREFECTURE (CUMULATIVE USABLE ROAD DISTANCES (METERS) AND RATIOS)

	Mar 31	Apr 08	Apr 15	Apr 22	Apr 29	May 27	Jun 24	Jul 29	Aug 26	Sep 30
Whole	3710404.71	4070465.56	4302746.51	4432316.59	4555942.55	4689705.40	4784541.96	4853809.92	4898789.43	4951562.17
Inland	0.749	0.822	0.869	0.895	0.920	0.947	0.966	0.980	0.989	1.000
Northern	689499.47	760734.33	798356.91	820800.18	861329.64	884760.76	917857.84	938069.52	946266.16	959149.12
Coastal	0.719	0.793	0.832	0.856	0.898	0.922	0.957	0.978	0.987	1.000
Southern	1401296.10	1501843.72	1544385.42	1576106.64	1589184.41	1610740.67	1621919.88	1634768.72	1639012.45	1643175.95
Coastal	0.853	0.914	0.940	0.959	0.967	0.980	0.987	0.995	0.997	1.000

TABLE II
REGIONAL DIFFERENCE FOR ROAD RECOVERY IN IWATE PREFECTURE (CUMULATIVE USABLE ROAD DISTANCES (METERS) AND RATIOS) [3]

	Mar 31	Apr 08	Apr 15	Apr 22	Apr 29	May 27	Jun 24	Jul 29	Aug 26	Sep 30
Northern	1850873.51	2070475.04	2152283.40	2251706.55	2296780.33	2403134.24	2483876.38	2532471.47	2571798.73	2603629.91
inland	0.711	0.795	*0.827*	0.865	0.882	*0.923*	0.954	0.973	0.988	1.000
Southern	2386739.37	2722218.13	2870724.95	2991566.34	3074037.86	3201569.09	3310978.41	3396994.03	3429255.89	3465835.57
inland	0.689	0.785	*0.828*	0.863	0.887	*0.924*	0.955	0.980	0.989	1.000
Northern	394082.91	449373.30	471389.15	524694.94	564884.21	589275.55	614317.97	618734.27	668603.07	675390.65
coastal	0.583	0.665	0.698	0.777	*0.836*	0.872	*0.910*	0.916	0.990	1.000
Southern	666655.53	779216.76	814157.35	821573.46	843427.24	855066.71	903310.83	910464.22	920120.72	934580.47
coastal	0.713	*0.834*	0.871	0.879	*0.902*	0.915	0.967	0.974	0.985	1.000

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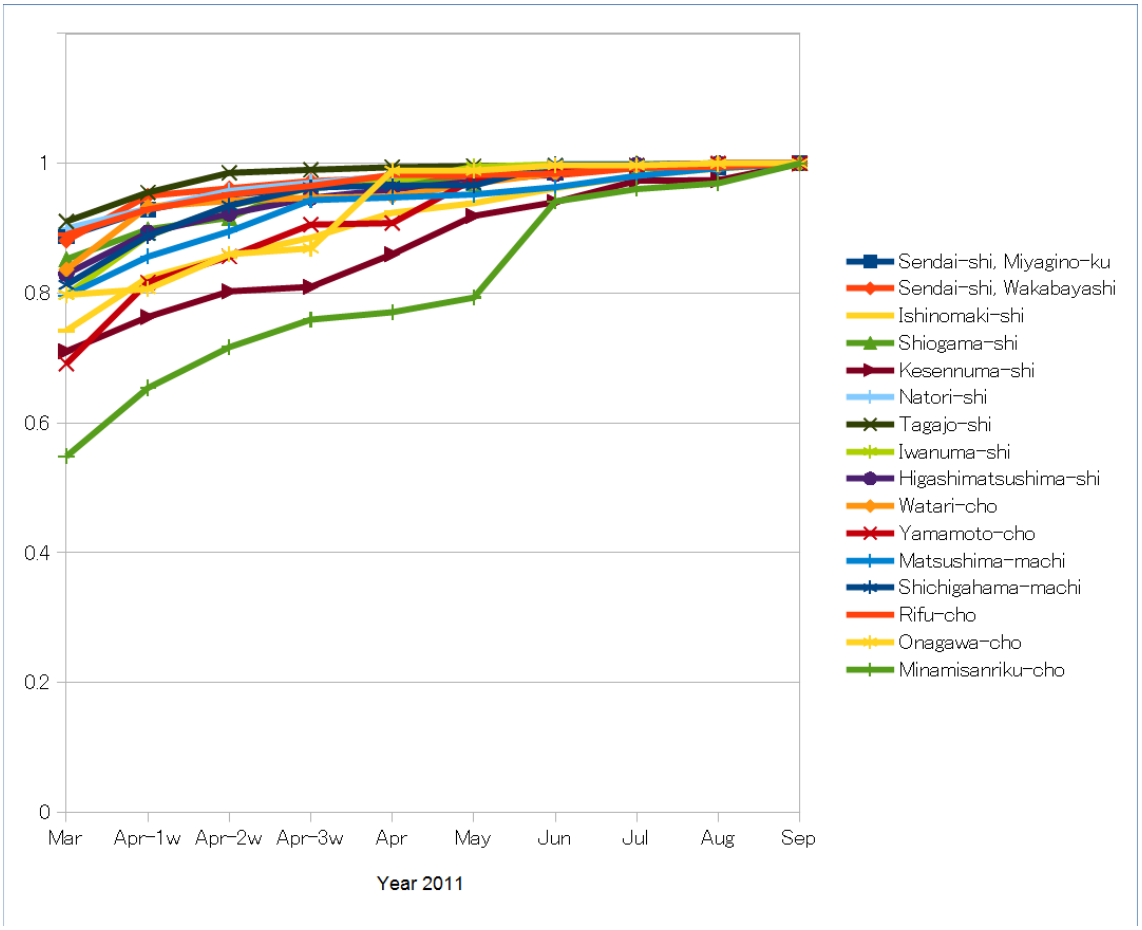

Fig. 5. Cumulative usable road distance ratio for the Coastal area. The vertical scale displays the cumulative distance proportion of the usable roads (relative to the cumulative distance on September 30, 2011) for each date.

-The route that runs through National Route 398, Sakuraba-shukaijyo, Doujishita-shikinosato, and National Route 398

For Kesen-numa City, the roads whose recovery was significantly delayed are as follows.

-The road to Nakai and Karakuwa from Miyagi Prefectural Road number 26 (Kesennuma-Karakuwa line)

-The roads near Minami Kesennuma Station (Kesennuma Line of the Japan Railway Company) and Uchinowaki

-Miyagi Prefectural Road number 26 (two sections: near Ootougeyama and near Atagoyama)

-Miyagi Prefectural Road number 26 (the section from Nakai Elementary School to the southern end of the route near Misaki Shrine)

3) Southern Coastal area [Fig.5]

The ratio increases in the usable distance of Matsushima Town was delayed significantly compared to those for other municipalities in the Miyagi Prefecture Coastal area. We were able to determine related roads by analyzing maps generated using QGIS software.

For Matsushima Town, the roads whose recovery was significantly delayed are as follows.

-The road from National Route 45 to Shintomi-yama

-The road from National Route 346 to the entrance of the tunnel near Hataya

-The road from Nakamachi to Shinden

VI. Discussion

A. Regional differences for the road recovery in Miyagi Prefecture

In the current study, we have evaluated regional differences in road recovery in Miyagi Prefecture following the 2011 Tohoku Earthquake. We divided Miyagi Prefecture into three areas, i.e., Inland, Northern Coastal, and Southern Coastal areas. Based on our evaluation results, we have concluded that the recovery conditions of regional roads following the 2011 Tohoku Earthquake differed based on area. In the Northern Coastal area, it was determined that 80% of the road distance was usable by April 15, 2011 and 90% was usable by May 27, 2011. On the other hand, in the Southern Coastal area, it was determined that 80% of the road distance was usable by March 31, 2011 and 90% was usable by April 8, 2011. Recovery in the Southern Coastal area was significantly faster compared to the Northern Coastal area.

The initial cumulative usable road ratio (relative to cumulative distance on September 30, 2011) calculated on March 31 was 0.72 in the Northern Coastal area compared to 0.85 in the Southern Coastal area. The difference decreased until April 29, 2011. Nevertheless, it took considerable time before normal road conditions were restored in the Northern Coastal area.

We assume that this difference was related to differences in the height of the tsunami's inundation [6] [Fig.6]. The coastlines observed in the Northern coastal area are primarily

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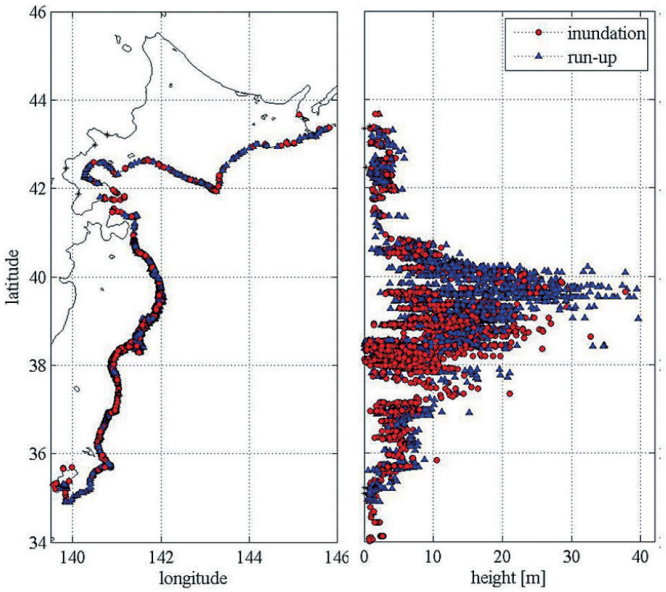

Fig. 6. Tsunami inundation following the 2011 Tohoku Earthquake. The left shows examination points. The right shows inundation and run-up (meters) of the points (cited from The 2011 Tohoku Earthquake Tsunami Joint Survey Group 2011 [6]).

characterized by rias. On the other hand, the coastlines observed in the Southern coastal area are primarily sandy.

The coastal shape influences the height of the tsunami. Subsequently, the height of the tsunami influences the amount of damage to roads and land.

B. Comparison of regional differences for road recovery in Miyagi Prefecture and Iwate Prefecture

According to the results of our study, we have concluded that the recovery conditions of the regional roads following the 2011 Tohoku Earthquake in the Northern Coastal area of Miyagi Prefecture were similar to those in the Southern Coastal area of Iwate Prefecture [Tables I and II].

We assume that this is because these regions border each other and their geographical features are similar. Furthermore, the recovery conditions of the regional roads following the 2011 Tohoku Earthquake in the Inland area of Miyagi Prefecture were similar to those in the Northern and Southern Inland area of Iwate Prefecture [Tables I and II].

As discussed in this section, in the disaster regions, similar recovery conditions were found according to geographic positions and features.

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