Disaster Risk Analysis of the Emergency Transportation Road for Large-scale Disasters in Japan

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大規模災害を対象とした緊急輸送道路の災害リスク分析

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Abstract

The emergency transportation road is connected with the expressways, general highways and main roads and also linked together with disaster prevention bases those are designated by the government. Although emergency transportation road is a cornerstone of emergency transport, the research of vulnerability for disaster risk of emergency transportation roads has not been sufficiently carried out so far. In this study, we analyzed the disaster risk of emergency transportation roads regarding the flood and building collapse those are responsible for road blockage caused by river flooding and earthquake respectively. Based on the analysis of disaster risk, we analyzed reachability of emergency transportation road between the prefectural and municipal offices. The target area of the study is the six prefectures namely Ishikawa, Toyama, Fukui, Niigata, Nagano and Gifu. The network analysis of impassable section of the emergency transport road that could be flooded by the river flooding, except the Niigata and Nagano Prefecture, it is revealed that more than 80% was unreachable between the disaster prevention bases e.g. prefecture and municipal offices. In the analysis of the building collapsed by earthquake that make road blockage, we considered the road-side building of emergency transportation roads. For the building collapse, we take the measurement seismic intensity which is a 2% exceedance probability for 50 years. Among the wide range of six prefectures, the maximum unreachability cases occurred in the municipal offices of Niigata and Nagano Prefecture.

1. Research Background

1.1 Introduction

Historically, destructive natural disasters have posed the greatest challenge for Japanese society. Unfavorable geographical, topographical and meteorological conditions of the country have made it one of the most disaster prone countries in the world. Although its territory accounts merely for the 0.25 % of the planet's land area, Japan is subject to about 20 % earthquakes with the magnitude 6 or more and 7 % the world's active volcanoes is located on its territory. The most frequent natural hazards in Japan are earthquakes, tsunamis, typhoons, volcano eruptions, floods and landslides. Occasional torrential rains and heavy snows are another challenge for the country. Based on the lessons of Japan's Great Hanshin-Awaji Earthquake, emergency transportation routes set to provide rescuing activities and transportation of goods immediately after the occurrence of earthquakes. The emergency transportation routes connect with the expressways, general highways and main roads and also links together with disaster prevention bases those are designated by the government. Although emergency transportation route is a cornerstone of emergency transport, research of vulnerability as a road network for disaster risk and disasters of emergency transportation route has not been sufficiently carried out so far.

1.2 Disasters and it's affect in the word

Disasters are events of huge magnitude and negative impacts on society and the environment. Disaster is also defined as a crisis situation causing widespread damage which far exceeds our ability to recover (Wassenhove, Van L.N, 2006). Disasters affect communities and nations, causing human life losses and material damages. One classification of disasters includes the following four causes (Star, 2007) namely; by human error and technological failures, by intentional malevolence, by acts of nature, and combinations of some or all the previous. Regarding by acts of nature, the International Disaster Database EM-DAT categorized the natural disaster into 5 sub-groups, which in turn cover 12 disaster types and more than 30 sub-types (Figure 1).

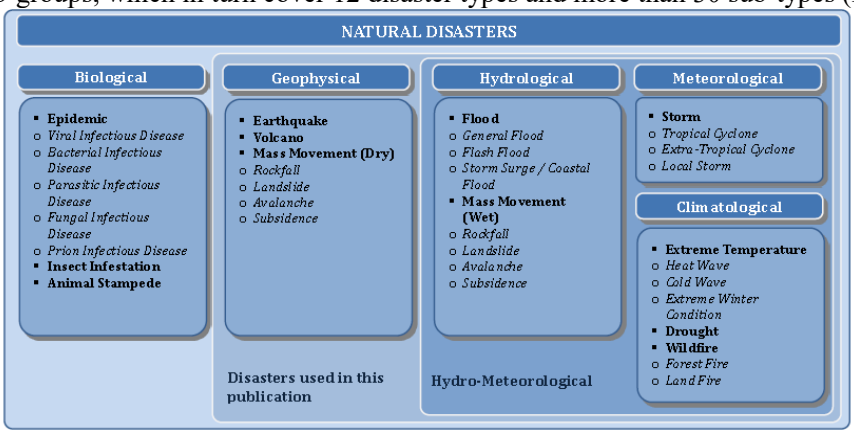


Figure 1: Natural disaster classifications (Annual Disaster Statistical Data 2012; EMDAT)

In the last four decades, based on the International Disaster Database (EM-DAT), between 1970-1979 and 2000-2012, the number of natural disaster events reported globally increased significantly from 837 to 4,939 or increased almost six times. Over the whole period of 1970-2012, 40.8 percent of these natural disasters occurred in Asia.

2. Disasters in Japan

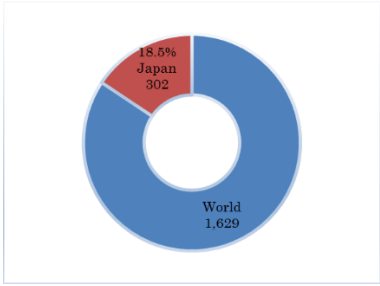
2.1 Introduction

In recent years, natural disasters occur frequently in Japan. Not only the large-scale low-frequency disaster like earthquakes or eruption, but also the small-scale high-frequency disaster like landslides or flood occurs

frequently accompanied by the heavy rain or localized torrential rain. Japan is located in the Circum-Pacific Mobile Belt where seismic and volcanic activities occur constantly. In addition, because of geographical, topographical and meteorological conditions, the country is subject to frequent natural disaster such as typhoons, torrential rains and heavy snowfalls, as well as earthquakes and tsunami. Some natural disasters that occur recently in Japan like the Great East Japan Earthquake (11 Mar. 2011), overflow of the Kinugawa River (10 Sep. 2015), and Hiroshima Landslide (20 Aug. 2014) are remarkable.

2.2 The ratio of natural disasters in Japan to those in of the world (Earthquakes and Volcanoes)

Among the countries of the world which suffer the most violent forces unleashed by nature, mention must unquestionably be made of Japan, with an abundant record of catastrophic events, produced on some occasions by earthquakes and on others by volcanoes, typhoons or tsunamis.
In Japan, of all the damaged produced between 1955 and 2004 by natural disasters, 2% were due to flooding, 22% to wind and 76% to earthquakes (Kikugawa, H. and Bienkiewicz; 2005). Although Japan takes up only 0.25% of the earth's surface area, it is the focus for a large percentage of the world's earthquakes and volcanoes. 18.5% of earthquakes of magnitude 6 or more have occurred in Japan (2004-2013), where 7.1% of active volcanoes (2014) are also concentrated here (Disaster Management Cabinet Office, 2014, Japan). It is shown in figure 2 and 3.



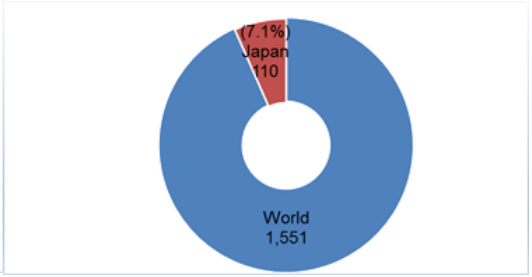


Figure 2: No. of earthquakes with magnitude of 6.0 or greater (2004-2013) **Figure 3:** Number of active volcanoes (2014)

2.3 Deaths and missing persons caused by natural disaster in Japan

Disasters cause death, economic and environmental damage, and severe setbacks for social development. Recent large-scale disasters, including the devastating earthquake and tsunami in Japan of March 2011, highlight the value of national preparedness for disaster. Figure 4 shows the number of deaths and missing persons by type of disaster (Past 20 years: 1994-2013)

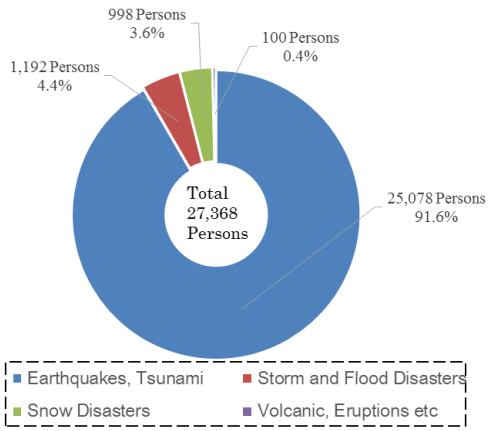


Figure 4: The number of deaths and missing persons by type of disaster (Past 20years:1994-2013)

3. Disaster Risk Analysis of Emergency Transportation Road (ETR) Network to Various Hazards in Japan

3.1 Introduction

In Japan, a natural disaster occurs frequently in recent years. An emergency transportation road network is designated for a large-scale seismic hazard, and a network is maintained so that it may become possible to do smooth transportation of goods when a large-scale disaster happens in Japan. However, while frequency and the kind of accidents are diverse, emergency transportation roads are not quantitatively grasped how degree they have a disaster risk. In this study, the risk of emergency transportation road network were quantitatively evaluated considering the various hazards such as earthquakes, floods, landslides, tsunami, volcanic and storm surges.

3.2 Emergency transportation road in Japan

The emergency transport road is categorized of primary, secondary and tertiary for each prefecture. It is seen a little difference in the name and selection criteria, but basically primary road covers the wide area range of high-speed automobile national highway, the general national highway and the trunk road. Then it shapes such a way that secondary and tertiary type can connect with primary road and also can communicate mutually between the disaster prevention bases as well as with the government offices. Table 1 shows the total length of each specified rank of emergency transportation road.

Table 1: The total length of each specified rank

(Unit:km)	National highway & Highway	Prefectural road	Municipal roads	Total length
Primary	45928.63	8077.59	1063.4	55069.62
Secondary	13368.92	22380.69	2428.48	38178.09
Tertiary	799.69	3152.69	714.29	4666.67
Unspecified	93.58	23.11	—	116.69
Total	60190.82	33634.08	4206.17	98031.07

3.3 The disaster risk due to earthquake

For an earthquake, the results of the analysis of these roads were overlapped within the predicted seismic intensity distribution. Emergency transport roads were overlapped in each evaluation criteria listed in figure 5, where ① –④ denotes a hit probability by earthquake on the emergency transportation road is divided by color into 10 stages at the range of 0 to 1 about each of seismic intensity a little less than 5, a little more than 5, a little less than 6 and a little more than 6. ⑤ –⑩ are divided by color into 6 stages of seismic intensity less than 4.5 to more than 6.5 about the hit assumption on the emergency transportation road with exceedance probability of 30 years and 50 years. In any case, the Pacific side showed a dangerously high value of risk, and, at every measurement of seismic intensity, it is added to the Pacific side again, and even the Itoigawa–Shizuoka tectonic line was found to possess a large disaster risk in ③. In case of the probability of the occurrence of an earthquake with a seismic intensity less than 6, it is observed that the risk of the Kanto region is large, followed by Tokai. The risk of a capital earthquake directly above the focus in addition to Tokai and Tonankai region was also observed.

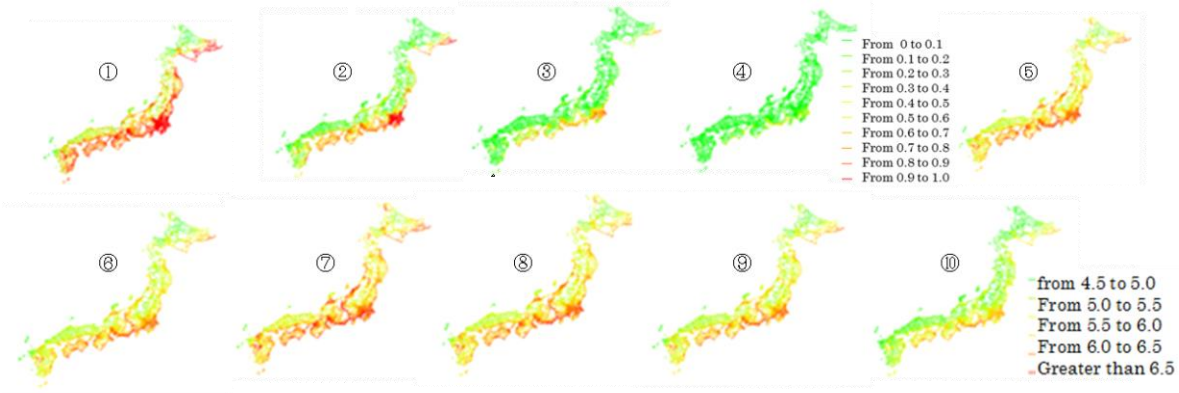


Figure 5: Disaster risk of emergency transportation road viewed in difference prediction seismic intensity

3.4 The disaster risk due to landslides

For landslides, the overlap ratio of the emergency transportation roads and landslide danger zone was analyzed to determine the disaster risk in every metropolis and district. In addition, the overlap ratio was given by: (the extension of the emergency transport roads are duplicated in each hazard area) / (total extension of emergency transportation road). The disaster risk for each portion of an avalanche such as debris flow, steep slope place collapse, and landslide was also studied. Furthermore, the aggregate result of the primary road alone has been described in this paper. Figure 6 shows a graph that plots the overlap ratio for each item on the primary road.

Figure 6: Overlap ratio of landslide disaster and emergency transportation road (primary road)

From Figure 6, it can be observed that the overlap ratios in the Chubu, Chugoku, and Shikoku districts were distinctly larger. Additionally, it can be noted that the Nagano prefecture has the highest ratio of debris flow compared to other prefectures. When comparing the highest values of each factor among different prefectures, it is revealed that the debris flow in the Nagano prefecture, steep slope collapse in the Yamaguchi prefecture, landslides in the Tokushima prefecture, and avalanche in the Gifu prefecture has resulted in most overlap. The analysis of the overlap ratio for each item for the secondary road can be seen in Figure 7.

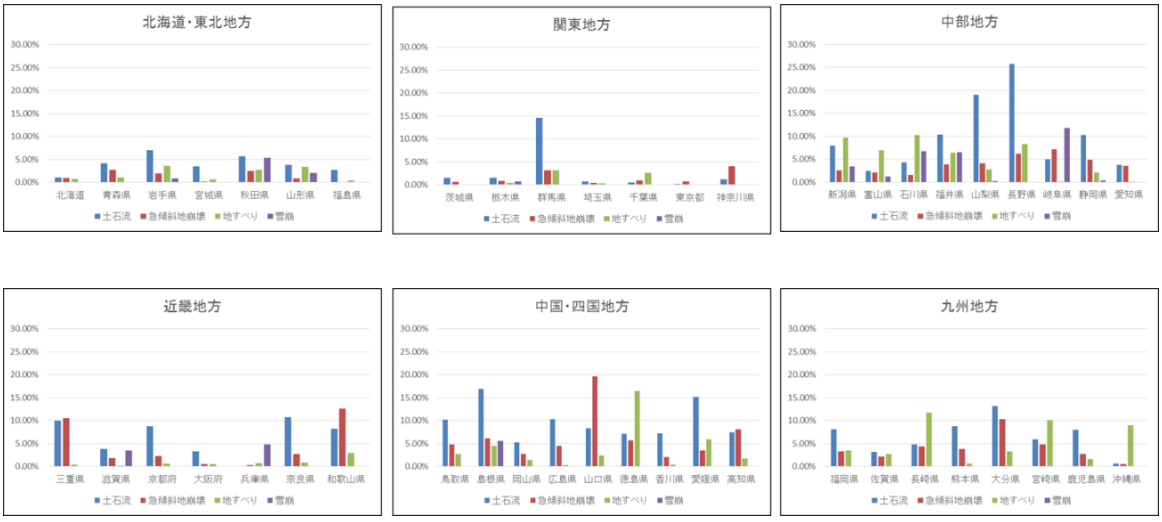


Figure 7: Overlap ratio of landslide disaster and emergency transportation road (Secondary road)

The secondary road does not show a large difference in values when compared to each item of the primary road. While the risk of avalanche or landslide seems to have increased, the overall risk of each item has increased only

slightly in most of the metropolitan cities and districts. The latter has a higher percentage of prefectural and municipal roads when compared to the former, and the reason behind the increasing percentage is that the roads chosen here are mountainous in nature. Additionally, it must be considered that the width of mountainous roads is smaller and slanted lines are lesser in number when compared to the roads in the city. For these reasons, there is a high risk of the road becoming impassable to traffic because of a landslide. Figure 8 shows a graph analyzing the overlap ratio for each item for the tertiary road.

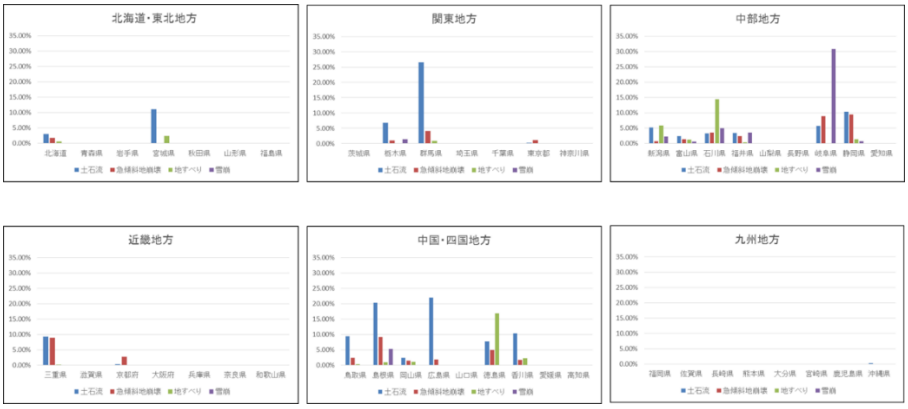


Figure 8: Overlap ratio of landslide disaster and emergency transportation road (Tertiary road)

For studying the tertiary road, we have analyzed 18 selected metropolitan cities and districts. Compared to the primary and secondary roads, it is observed that there is a larger disaster risk in different parts because of an avalanche in the Gifu prefecture. As avalanches cause widespread damage, it seems that the road also becomes impassable at wide range in the same way. There is a high risk of avalanches in the case where the slope gradient is 35–45 degrees and consists of sparse vegetation, compared to slopes with shrubs and forests. It can be assumed that tertiary roads in the mountainous areas are concentrated on slopes such as the ones described above. The drop in the supplementation and the lack of function of the emergency transportation road in the metropolitan cities and districts is the result of the high disaster risk of the tertiary road.

3.5 Disaster risk due to flood

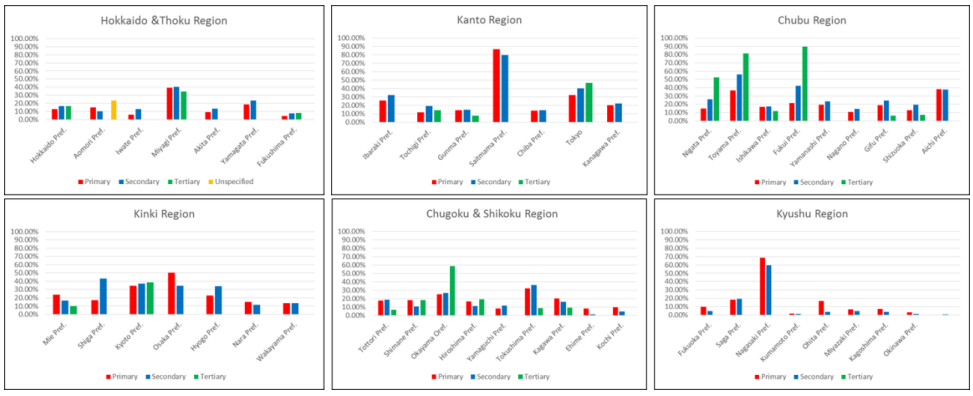


Figure 9: Overlap ratio of flood estimated areas and emergency transport roads

Similar to the disaster risk due to landslide, the duplicate ratio was analyzed by considering the flood assumption area and emergency transportation road in every prefecture. It can be noted that the disaster risk was analyzed by defining 'flooded' with 0.5 m for flood estimated areas, using data with boundaries of 0.5 m, 1 m, 2 m, and 5 m. This study was also designed to be consider transportation by car, with the exhaust port and non-driving motors completely flooded, to specify the rank. Figure 9 shows the graph that sums up the duplicate ratio for every designated rank.

Both primary and secondary roads show a higher overlap ratio in the Saitama prefecture, and the tertiary road showed a higher overlap ratio in the Niigata prefecture and the Hokuriku region of the Toyama prefecture. It should be noted that in the Saitama prefecture, the roads are concentrated around the river, which increases the risk of flooding due to overflowing. For the Hokuriku region, rainfall throughout the year is definitely a factor to consider. For the Toyama and Niigata prefectures, as the selection criteria for the tertiary road, the primary and secondary roads are set up here to contact the disaster prevention bases. This means that the overlap ratio of tertiary roads is high along emergency transportation roads, indicating that high disaster risks could be found in the areas around the disaster prevention centers.

4. Reachability Analysis between Prefectural Office and Municipal Offices while Considering the Disaster Risk of ETR

4.1. Evaluation method of the disaster risk of ETR and construction method of the ETR network

(1) Data source of emergency transportation road network

In this study, we use the emergency transportation roads of the national numerical land information data. These data is to create a route shape, division of the emergency transportation road, road classification, a route name using a local disaster prevention plan, the documentation about the emergency transportation road network plan which are organized by the metropolis and districts.

(2) Evaluation method of the disaster risk of ETR caused by the river flooding

In this study in order to assess the flood damage of ETR, it has been received the use of anticipated flooding zone data of the country numerical information inundation assumption area and assumed inundation depth at the national scale. Inundation is divided into 5 or 7 level shown in table 2.The situation where the road becomes unusable by flooding, in this study it is defined as the depth of immersion; car becomes impossible of traveling. Generally, depth immersion of the automobile is unable traveling are the depth of the floor of the vehicle are flooded. Therefore, of the Table 2, to evaluate as a section that emergency transportation road inundation depth to exist in inundation assumed within the area that fall into more than 0.5m may become unusable by flooding when the rivers flood. In addition, the flood zone of emergency transportation road, as shown in Figure 10, the emergency transport roads and inundation assumption area data of the country numerical information when it is piled up on a GIS, both of interval were completely matched.

Table 2: Inundation depth level and road conditions

Inundation Depth Level		Road Condition
5 Levels	7 Levels	
below 0 ~ 0.5m	below 0 ~ 0.5m	Not flooded
below 0.5m ~ 1.0	below 0.5m ~ 1.0m	Flooded
below 1.0 ~ 2.0m	below 1.0m ~ 2.0m	
below 2.0m ~ 5.0m	below 2.0m ~ 3.0m	
above 5.0m	below 3.0m ~ 4.0m	
	below 4.0m ~ 5.0m	
	above 5.0m	

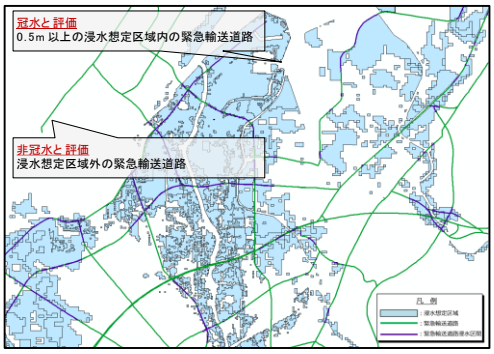


Figure 10: Conceptual diagram of the inundation zone of ETR

(3) Evaluation method of the risk related to building collapse and road blockage caused by earthquake

Another factor that emergency transportation road becomes unusable, it is thought that buildings along the roadside comes to collapse on emergency transportation road at the time of the earthquake. To evaluate the risk of a road obstruction by buildings collapsed, it is required the data of the position and height of building, construction time and about structure of the building, etc. Such kind of data is what is readily available with a

limited amount of information, if further directed to a wide range of area as in this study, the data's availability is almost nil The data about the desired building are included in this study in that, and a kind and the height of the building are compiled into a database. Incidentally, the height of the building has been considered by one floor per 3m, the type of buildings are uniquely classified. Such data can take advantage of the position and height as possible grasp the building data. It shows the data of the above example in Figure 11.

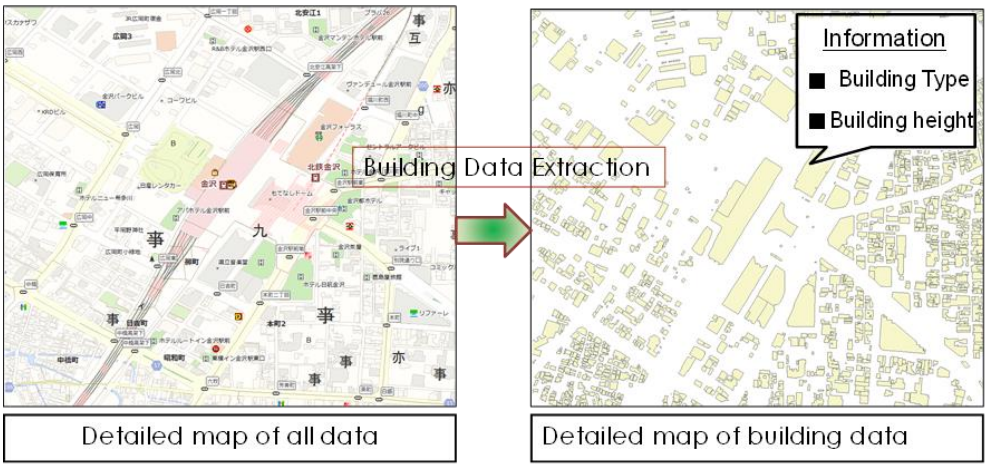


Figure 11: Example of all detailed map data and building data

The structure type of the building, were classified as wooden and non-wooden according to the classification of the data. The building of classification that are assigned to the residence was a wooden, but also includes high-rise dwellings, such as apartment in this classification. For this reason, the fourth floor or more of the building (building height is more than 9m) it was classified as non-wooden. It shows the extraction flow diagram of the building that affect the emergency transportation road in Figure 12. Extraction of the building, to determine the center of gravity of the building, from the center of gravity obtained, after drawing a circle to the height of the building as a radius, affects the emergency transportation roads the building when including emergency transportation roads within the circle.

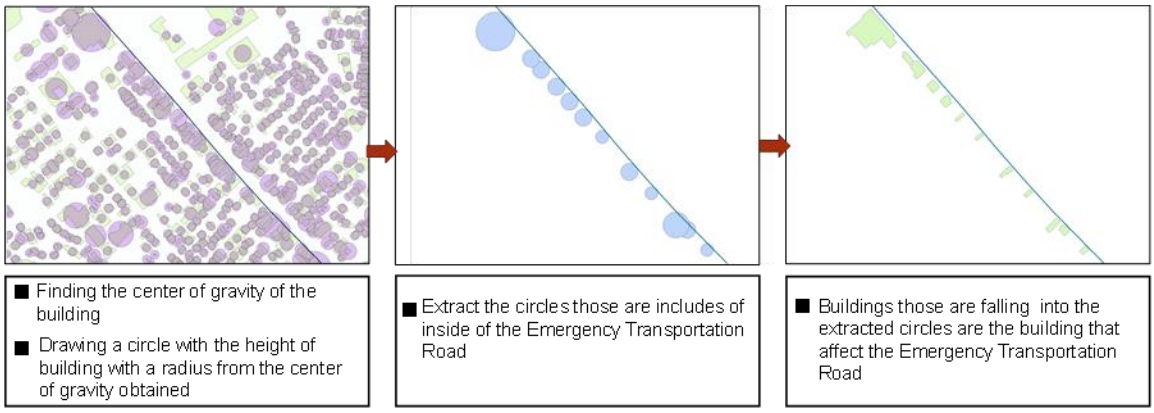


Figure 12: Extraction flow diagram of the building that affect the emergency transportation road

In order to evaluate the risk, for these data, it applies the damage function of the building due to an earthquake, to determine the total collapse probability of each building. Then the random simulation, it is determined whether or not the building is destroyed, if it is destroyed then assessed that building occurs a road blockage in the emergency transportation roads adjacent.

4.2 Analysis of reachability between Prefectural and municipal offices

(1) The target area, factors of disasters and impassable of emergency transportation road, and municipal offices.

In the present study, the target area is intended for Niigata, Toyama, Ishikawa, Fukui, Nagano and Gifu Prefecture. Figure 13 shows the emergency transport road network of peace time and it is studied by each prefecture. It is intended for disaster in both river flooding caused by earthquake and rainfall and complex cases. The impassable factors of emergency transportation road, it is assumed and the obstruction of emergency transportation road caused by the collapsed of the road side building by an earthquake, a flood of emergency transportation road by the river flooding. It indicates the number of local government office that targets in Table 3. Municipal office was set on the basis of the municipal office data of national digital land information.

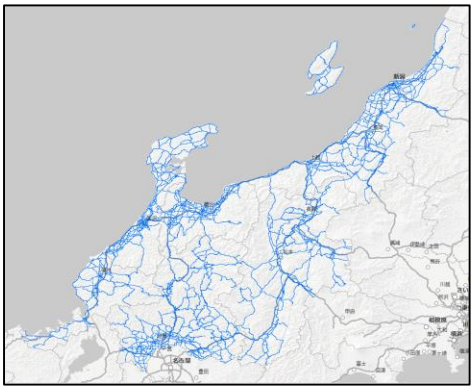


Figure 13: Emergency transportation road network diagram of peace time in the target area

Table 3: The number of targeted municipal offices of 6 prefectures to be analyzed

Niigata	Toyama	Ishikawa	Fukui	Nagano	Gifu
36	15	19	17	77	42

(2) Analysis of reachability between the prefectural government and the local government offices in consideration of the flood.

The emergency transportation road section that may flood is caused by river flooding in Figure 14, we show the emergency transportation road network in consideration of immersion depth was evaluated as it is described in section 4.1(2) in which there is a risk of flooding the road section to be than 0.5m

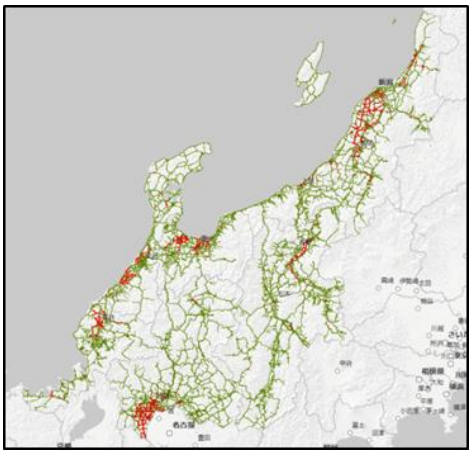


Figure 14: Emergency transportation road network diagram in consideration of the flood risk

It is revealed the effect to the reachability in this study, from the Prefectural Government office using emergency transportation roads to each local government office trying to reach emergency transport roads in the case of river flooding. Therefore, the data is shown all emergency transportation roads contained 0.5 m or more in the flooding expected area. The flooding is expected in the area of sections impassable due to flooding. In Table 4, it shows the numbers of unreachability and delays to the municipality offices while considering the flood risk of emergency transportation road.

Table 4: Numbers of unreachability and delays to the municipality offices while considering the flood risk of ETR

Prefectures	Niigata	Toyama	Ishikawa	Fukui	Nagano	Gifu
Target no. of municipal offices	36	15	19	17	77	42
Number of unreachability	16	14	16	16	35	41
Percentage of unreachability	44.4%	93.3%	84.2%	94.1%	45.5%	97.6%
Number of delays	18	0	2	1	35	0
Percentage of delays	50.0%	0.0%	10.5%	5.9%	45.5%	0.0%

In addition, it shows the service area from the normal time of the prefectural government at the time of flooding consider using emergency transportation road network of six prefectures that targets in Figure 13. From Table 4, it suggests that the flood risk that could become unreachable on emergency transportation road connecting the prefectural government and municipal office in any province is abundant. In particular, Toyama, Fukui, Gifu, local government office that can be reached without the risk in and in Ishikawa Prefecture it is limited. As Toyama, Fukui, Gifu Prefecture is gone through the river near the prefectural government, for emergency transportation road with flood risk is dense.

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(3) Analysis of reachability between Prefectural government and municipal office in consideration of buildings collapsed that make the road blockage by the earthquake.

As we consider the building collapsed due to an earthquake, in the present study measuring seismic intensity distribution in the case of a 2 percent 50-year exceedance probability of the J-SHIS earthquake hazard station probabilistic seismic hazard map is used. In addition, demolished rate curve (Figure 15, Figure 16) that have been shown in Tokyo and disaster prevention envisioned as damage function of the building was adopted.

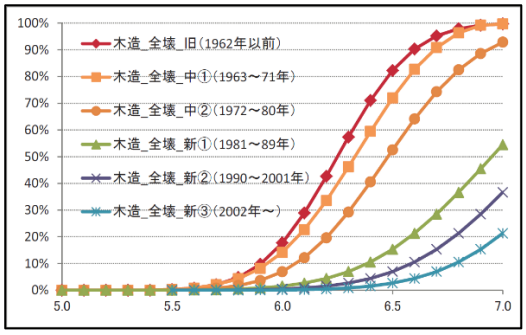

Figure 15: Fragility curves of wooden building

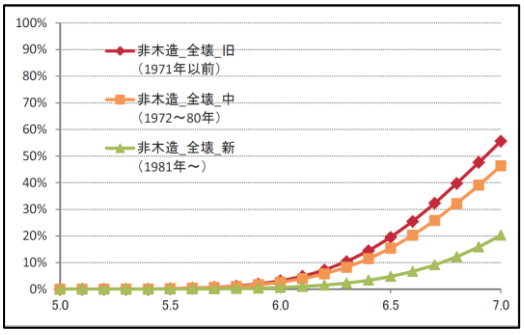

Figure 16: Fragility curves of non-wooden building

Numbers, of buildings along emergency transport roads, 0 to 100 in increments of 0.1 random-number generation,

exceeding the rate of collapse occurs and completely destroyed the building, choking emergency transport roads adjacent to a building collapse simulation. Emergency transport road network by considering the road blockages shown in Figure17.

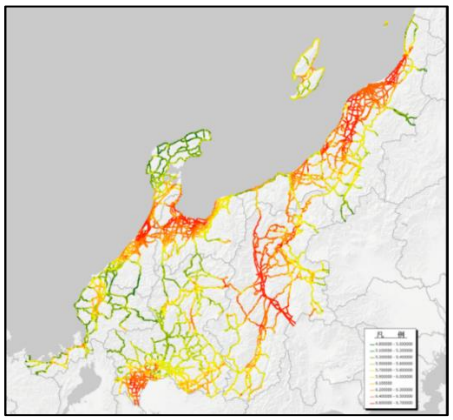

Figure 17: Distribution on ETR of measuring seismic intensity which is a 2% of 50years exceedance probability

In addition, emergency transportation roads such high seismic intensity is expected to be present enough in the network is sparse part. It cannot be substitute any other emergency transport roads resulted from collapsed buildings in these areas. There are some partially unreachable regions too.

Table 5: Number of unreachability and delays to the municipal offices when considering the building collapsed and road blockage caused by the earthquake

Prefectures	Niigata	Toyama	Ishikawa	Fukui	Nagano	Gifu
Target no. of municipal offices	36	15	19	17	77	42
Number of unreachability	3	1	0	0	9	0
Percentage of unreachability	8.3%	6.7%	0.0%	0.0%	11.7%	0.0%
Number of delays	9	14	19	17	58	42
Percentage of delays	25.0%	93.3%	100.0%	100.0%	75.3%	100.0%

5. Conclusion

In this study, we analyzed the disaster vulnerability of emergency transportation roads regarding the flood and building collapse which are responsible for road blockage caused by river flooding and earthquake respectively. Based on the analysis of disaster risk, we further analyzed reachability of emergency transportation road between the prefectural and municipal offices. The target area of the study is the six prefectures namely Ishikawa, Toyama, Fukui, Niigata, Nagano and Gifu. The network analysis of impassable section of the emergency transport road that could be flooded by the river flooding, except the Niigata and Nagano Prefecture, it is revealed that more than 80% was unreachable between the prefecture and municipal office. In particular, there is a threatening of flooding by the rivers those are flowing near the prefectural offices of Toyama, Fukui and Gifu prefecture. It is a possibility that many emergency transportation roads around the prefectural office could be flooded, that is why it became a result that it is impossible to reach the municipal offices from the prefecture. In the analysis of the building collapsed by earthquake that make road blockage, we considered the road-side building of emergency transportation roads. For the building collapse, we take the measurement seismic intensity which is a 2% exceedance probability for 50 years. Among the wide range of six prefectures, the maximum unreachability cases occurred in the municipal offices of Niigata and Nagano Prefecture.

平成２８年　２月　２日

学位論文審査報告書（乙）

１．学位論文題目（外国語の場合は和訳を付けること。）

Disaster Risk Analysis of the Emergency Transportation Road for Large-scale Disasters in Japan

（大規模災害を対象とした緊急輸送道路の災害リスク分析）

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３．審査結果の要旨（600～650字）

博士学位申請論文は、近年日本各地において頻発している大規模河川災害を対象とした河川災害リスク分析に関して研究を行ったものであり、時宜を得た非常に重要な研究といえる。本論文では、災害発生時に被災する可能性がある緊急輸送道路のリスク分析の評価方法を提案し、河川氾濫によるリスク、地震発生時の建物倒壊による道路閉塞のリスクを考慮した緊急輸送道路のリスク分析（県庁と市町村役場間の到達可能性分析）を行い、防災拠点（県庁）から想定される被災地（市町村役場）までの緊急輸送道路による登宅可能性評価を行ったものである。また、確率的には非常に発生頻度は低いと考えられるが両者の複合ケースによる到達不能地域についても推計を行っている。

また、実際に平成20年7月に発生した浅野川豪雨災害発生時の避難行動についても分析しており、行政の発する避難情報の在り方の課題についても明らかにしている。

これらの研究成果は、自然災害科学に１編掲載されている。なお、論文は英語で書かれており、審査会での発表も英語であるので、国際コミュニケーション能力については全く問題がない。よって、博士（学術）の学位を授与するに値すると判断した。

４．審査結果　(1) 判　定（いずれかに○印）　（合　格）・　不合格

(2) 授与学位　博　士（　学術　）

５．学位論文及び参考論文に不適切な引用や剽窃が無いことの確認

■　確認済み（確認方法：剽窃ソフトにより、不適切な引用、剽窃がないことを確認した　）

□　未 確 認（理　　由：　　）