16th World Conference on Earthquake Engineering, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 4816(Abstract ID)

Registration Code: S-K1464776213

A STUDY OF VULNERABILITY OF EMERGENCY TRANSPORTATION ROAD CONSIDERING THE COMPLEX DISASTER

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Abstract

Japanese local government has designated expressway, national highway, highway and road which mutually linked these one and disaster prevention facilities as Emergency Transportation Road, to carry out the emergency transportation which occurs immediately after an earthquake hits, based on the Great Hanshin/Awaji Earthquake in 1995. Emergency transportation was carried out not only when the earthquake has occurred but when the various disaster has occurred. Therefore, in high disaster risk countries like japan, the role to be played by the Emergency Transportation Road is very important. However, Emergency Transportation Road was only evaluated and designated aforementioned connectivity, disaster potential of Emergency Transportation Road was not taken into consideration. Furthermore, disaster potential of Emergency Transportation Road was not sufficiently considered. Therefore, existing emergency transportation plan that utilizes Emergency Transportation Road is supposed that cannot function as sufficient plan. It is necessary to make clear that disaster potential of Emergency Transportation Road, and need consideration whether emergency transportation is possible or impossible in view of like that the disaster potential. The present study discusses as follows: to evaluate the disaster potential of Emergency Transportation Road, to conduct an analysis of emergency transportation from each prefectural to municipal offices and evacuation facilities. With respect to disaster potential of Emergency Transportation Road, this paper provides an analysis of three types of disaster as shown below: first, road blockage caused by the building collapse due to an earthquake, second, inundation damage caused by river flooding owing to rainfall, finally, road blockage caused by sediment disaster. Divide these disaster into two cases, one is these disaster occurs alone, the other is these disaster generated in complex. In each case conduct an analysis of connectivity of Emergency Transportation Road network by simulation which used random number, and emergency transportation from each prefectural to evacuation facilities is considered. As a result of this study, it became clear that Emergency Transportation Road has high disaster potential. Therefore, it became clear that there is a possibility that emergency transport utilized Emergency Transportation Road network is difficult.

Keywords: emergency transportation road, complex disaster, vulnerability

1. Introduction

The capacity of roads in the affected areas was significantly diminished when Hyogo – ken Nanbu Earthquake occurred in January 17, 1995. by means of the collapse of elevated structures and roadside buildings and the destruction of roads. Moreover, the differ traffic demands from peacetime were occur in connection with evacuation activities, first aid activities and rescue, humanitarian aids and recovery and reconstruction efforts. Because of disaster of major highway, emergency transportation routes to compensate for these roads was set to the next day. However, it was practically difficult to regulate traffic only to emergency vehicles. These has been published as lesson materials [1] by cabinet office of Japan. In the light of this materials, the emergency transportation road has been set in which to emergency transportations that occurs just after the earthquake. As Table 1 shows, these has been set from Primary to Third according to the role [2].

Table 1 – Kind and role of emrgency transportation road

Kind	Role
Primary	Roads that forming of transport are as follows: Such Arterial high-standard highways and National routes as broad important routes
Secondary	Roads that connect Primary emergency transportation road with municipal offices and important bases
Third	Road that connect Primary and Secondary emergency transport with branches of municipal office

It is assumed that the road blockage caused by the collapsed of the roadside building when an earth quake occurs. In addition, it is supposed that roads become impassable by means of river flooding and sediment disasters such as the disaster other than earthquakes. It has been frequently studied with respect to road blockage caused by collapse of the roadside building so far. On the other hand, a study on impassable of the road in the event of a disaster, and an analysis of the reachability between certain two points in situation where there are impassable roads are crucial from the perspective of reachability in the event of a disaster between important bases. However, little study has been done to these perspectives. In this paper, it is analyzed for reachability between the prefectural office and evacuation facilities as important bases it should be reached in the event of a disaster. Supposed disasters are earthquake, river flooding, and sediment disaster. Moreover, impassable factors of the road in each of the disaster are collapse of roadside buildings, flooding of road, and Sediment disasters onto the road are considered for the analysis. Based on the result of this analysis, it is analyzed the reachability between prefectural office and evacuation facilities using emergency transportation roads network.

2. The construction method of emergency transportation roads network and the evaluation method of the disaster risk on emergency transportation road

2.1 The construction method of emergency transportation roads network

In this study, using the GIS data of emergency transportation road which has been published by National Land Numerical Information download service [3] to construct emergency transportation roads network. Based on the regional disaster prevention plans and the emergency transportation network plans, this data deals with the line shape, the classification, and the type of emergency transportation roads.

2.2 The evaluation method of the river flooding risk

To evaluate the river flooding risk on emergency transportation roads, it is used flood-assumed area data [4] which has been published by National Land Numerical Information download service on a nationwide scale. This data deals with range of flood-assumed area, flood depth, object river of plan and the design rainfall. Among these, flood depth is divided into 5 or 7 levels as shown in Table 2. In this study, the situation where the roads become impassable by flooding is defined as flood depth which vehicles become unable to travel. Such a flood depth is generally accepted that depth which the floor of the vehicle is submerged. In the light of this, the roads which in a flood-assumed area where flood depth is more than or equal to 0.5 meters is evaluated as segment that may be unusable by the flood. As Figure 1 shows, the flood segments of emergency transportation road are set to matched segments where superimposed emergency transportation road and flood-assumed area.

Table 2 – Graded flood depth and the flooding state of the road

Classification of flood depth		Flooding state
5 levels	7 levels	
fewer than 0.5 meters	fewer than 0.5 meters	non-flood
0.5 meters or more but fewer than 1.0 meters	0.5 meters or more but fewer than 1.0 meters	flood
1.0 meters or more but fewer than 2.0 meters	1.0 meters or more but fewer than 2.0 meters	flood
2.0 meters or more but fewer than 5.0 meters	2.0 meters or more but fewer than 3.0 meters	flood
5.0 meters or more	3.0 meters or more but fewer than 4.0 meters	flood
	4.0 meters or more but fewer than 5.0 meters	flood
	5.0 meters or more	flood

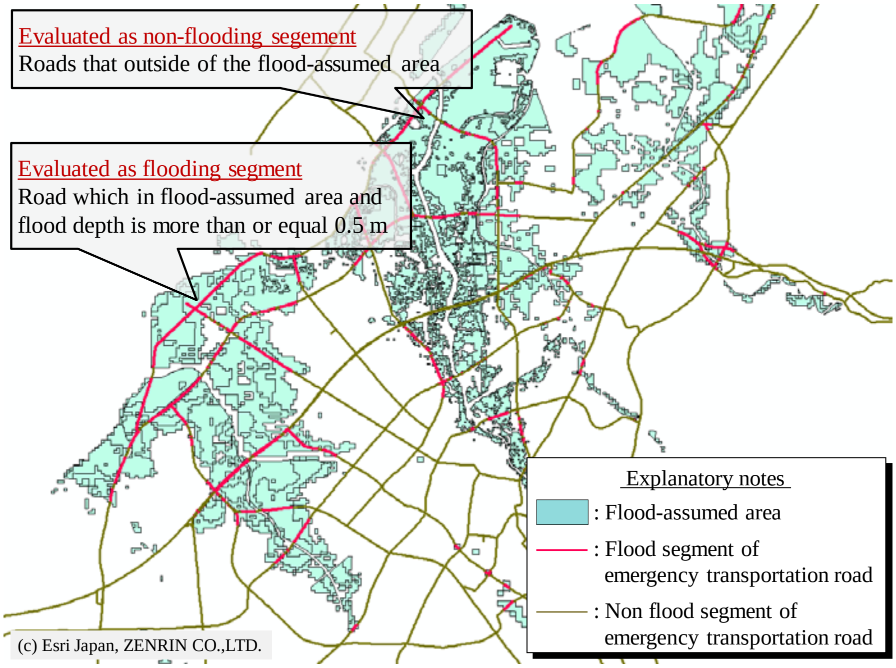

Fig.1 – Conceptual diagram of the evaluation of the flood segment

2.3 The evaluation method of risk of road blockage caused by collapse of roadside buildings

To evaluate the risk of road blockage caused by collapse of roadside buildings, it is needed data of buildings such as position, height, building date and structural type. However, it is generally difficult to obtain such data. For this reason, it is created building data that can be grasped height and position of building in this study. To create such data, it is used for *Detailed Map 2012* that provided by ESRI Japan [5]. An example of *Detailed Map 2012* and created building data is presented in Fig.2.

To risk evaluation of the building collapse, it is needed to data of structure and age of building. As is summarized in Table 3, structure of building is categorized in accordance with specification of *Detailed Map 2012*. The building that corresponded to a residence is wooden construction, however, this category is also included high-rise buildings like high-rise apartment. Because of this reason, the building more than four- storied is categorized into non-wooden construction. With respect to age of building determination method, the way which determined random based on current status of earthquake resistance, changed to parametric, and so on. The building data that created in this study has high-spatial resolution. It is called for data of age of building which has comparable spatial resolution to apply above-mentioned method. However, such data has not published. Therefore, it is supposed that all buildings are designed under the current building code. By this assumption, the road blockage risk caused by roadside building collapse as this study demonstrates is minimum case.

The building data that created in the above procedure included buildings that built along the road other than emergency transportation road. For this reason, it is extracted the building that built along emergency transportation road and used for analysis.

Next, decide the magnitude of ground motion in which each building is hit based on probabilistic seismic hazard maps that open to the public by *Japan Seismic Hazard Information Station* [6]. Furthermore, decide the probability complete destruction of each building on the basis of damage function of the building against earthquakes.

To evaluate the load blockage caused by collapse of roadside building, we carried out random number simulation using the above data. It performs a complete destruction judgment of each building, if the building is determined to completely destroyed, adjacent emergency transportation road become impassable.

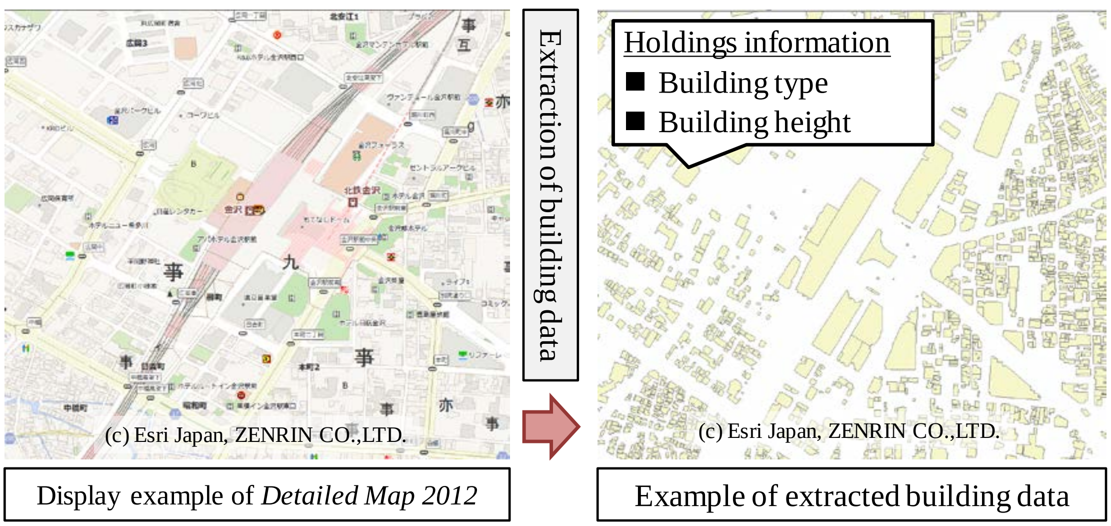

Fig.2 – Example of *Detailed Map 2012* amd building data

Table 3 – Building type and structure of building data in *Detailed Map 2012*

Building type	Structur of building	Building type	Structur of building
Landmark object (hotel)	non-wooden	Landmark object (public facilities)	non-wooden
Landmark object (commericial facilities)	non-wooden	Landmark object (medical care)	non-wooden
Landmark object (schol)	non-wooden	Landmark object (traffic)	non-wooden
Landmark object (sparetime and leisure)	non-wooden	Frame of the general house (other) 3-stories or less	wooden
landmark object (landmark object)	non-wooden	Frame of the general house (other) 4-stories or more	non-wooden

2.4 The evaluation method of risk of road blockage caused by sediment disaster

To assessed the risk of sediment disaster on emergency transportation road, in the same way as evaluation of river flooding risk, it is used sediment disaster hazard area data [7] which has been published by National Land Numerical Information download service. This data organized such as range of sediment disaster caution area, type of disaster and type of designation of sediment disaster caution area. As Figure 3 shows, damaged section due to sediment disaster is set to matched segments where superimposed emergency transportation road and sediment disaster caution area.

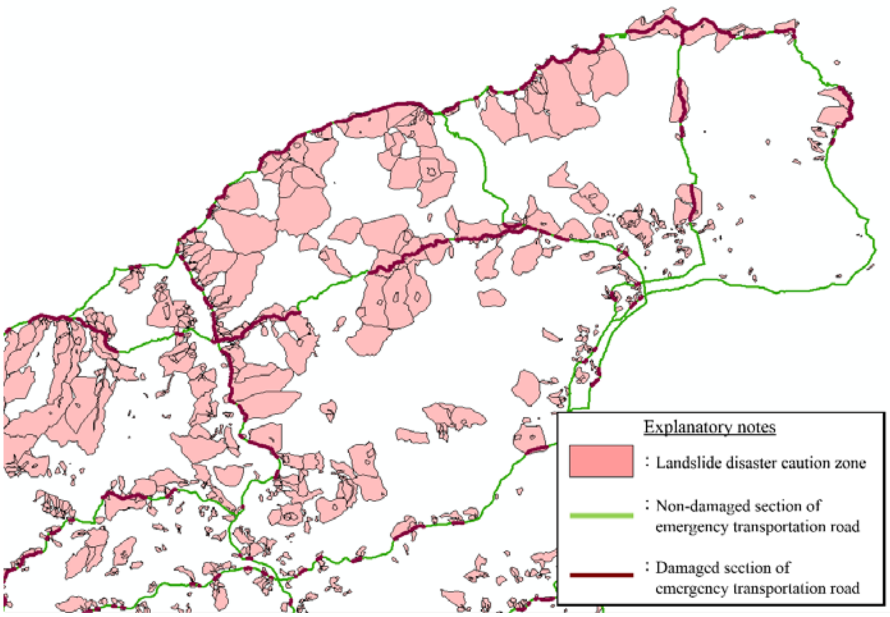

Fig.3 – Conceptual diagram of the evaluation of the risk of sediment disaster on emergency transportation road

2.5 The construction method of emergency transportation network considering the disaster risk

Figure 4 shows a conceptual diagram of construction method of emergency transportation road network considering the disaster risk. Such emergency transportation road network is removed the affected section from normal time network. In brief, the flooded road section, roadblock section caused by building collapse or sediment disasters is deleted. Moreover, to network analysis, it is needed to the link between the emergency transportation road network and the destination. This link created as the shortest straight line connecting from the destination to the nearest emergency transportation road.

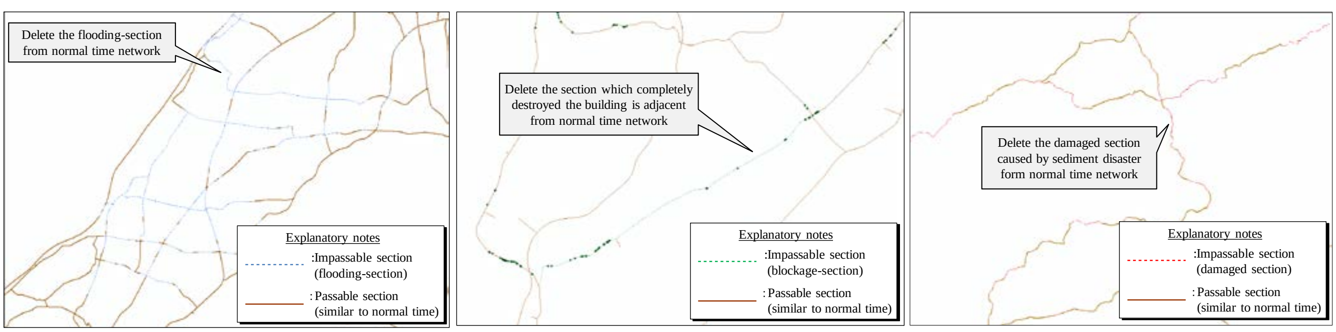

Fig.4 – Conceptal diagram of construction method of emergency transportation road network considdering the disaster risk

3. A reachability analysis between prefectural office and evacuation facilities

3.1 Analysis conditions for reachability analysis

Object area of this study is set to Niigata, Toyama, Ishikawa, Fukui and Gifu prefecture and it is constructed the normal time emergency transportation road network such as Fig.5 shows. Moreover, number of object evacuation facilities is presented as Table 4. Object disaster is earthquake, river flooding, sediment disaster and each complex disaster. Collapse of the road side building caused by earthquake, road flooding caused by the river flooding and road blockage caused by the sediment disaster are conceived as impassable of emergency transportation road. Moreover, by the occurrence of impassable section, even if the bypass cannot be reached from the prefectural office to evacuation facilities, it is assessed as state of unreachable that. Conversely, if it can reach the evacuation facility but reaching distance is increased owing to bypassed, it is assessed as state of delay. Note that state of delay is only focused on reach distance but increased of travel time is not taking into account.

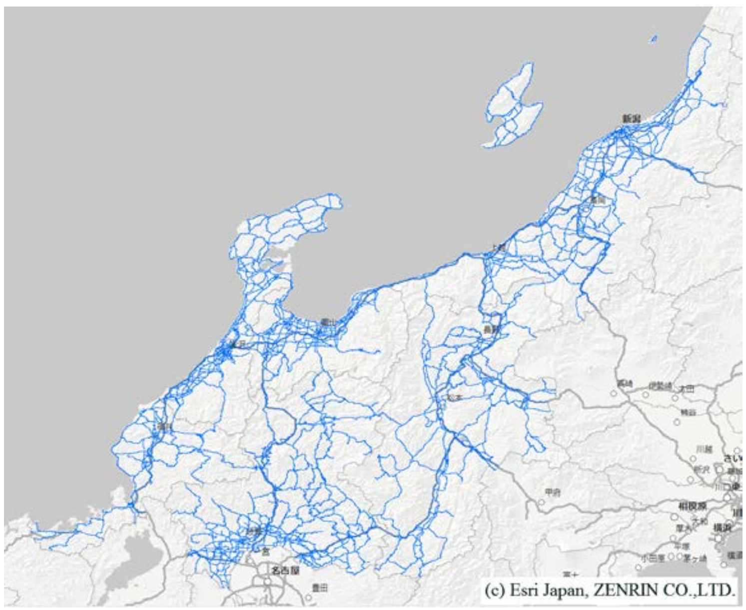

Fig.5 – Figure of emergency transportation road network in normal time

Table 4 – Number of the subject of evacuation facilities

Number of the subject of evacuation facilities					
Niigata Pref.	Toyama Pref.	Ishikawa Pref.	Fukui Pref.	Nagano Pref.	Gifu Pref.
2,853	1,197	1,022	1,509	3,822	2,906

3.2 Reachability analysis between prefectural office and evacuation facilities considering the emergency transportation road flooding

Emergency transportation road section that is likely to flooding and emergency transportation road network considering this flooding-road section is presented in Fig. 6. The aim of this study is to clarify the flood risk on emergency transportation road has influence on reachability. Therefore, all of emergency transportation sections that flood-depth conceived more than or equal 0.5 meters is set to impassable sections. The result of reachability analysis between prefectural office and evacuation facilities is presented in Table 5. Moreover, reachable area between prefectural office and evacuation facilities is presented in Fig 7. Based on Table 5, it seen that there many flood risk on emergency transportation road that influence on reachability. Following insights offered by Fig 7 and geographical features of the target area: First, there are many flood risk on emergency transportation road that positioned plain and nearby river. Second, if prefectural office is positioned plain and nearby river, it is great influence on reachability from the prefectural office to the outside. Finally, since many flood risk exists on emergency transportation road crossing the river, it is needed to ensure the alternate route.

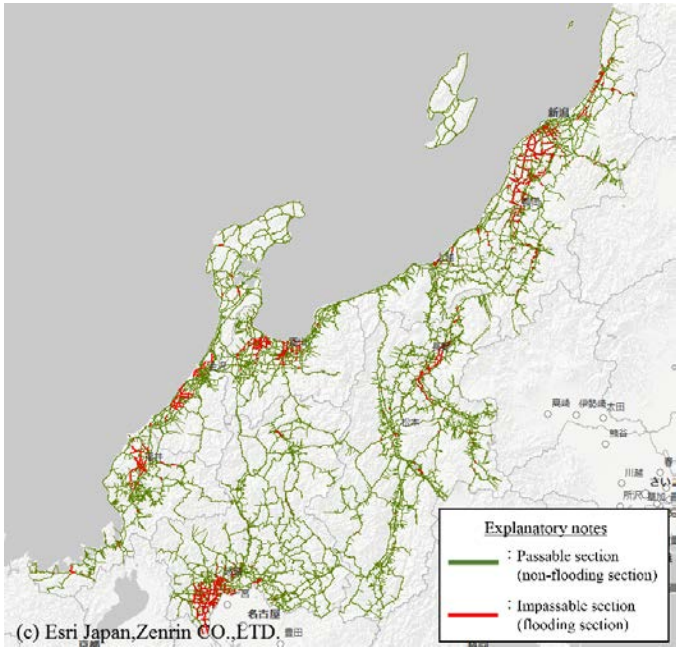

Fig.6 – Figure of emergency transportation road network considering the flood risk

Table 5 – Result of reachability analysis in case of considering the river flood

Prefectures	Niigata Pref.	Toyama Pref.	Ishikawa Pref.	Fukui Pref.	Nagano Pref.	Gifu Pref.
Number of subject of evacuation facilities	2,188	784	846	1,061	3,414	2,145
Number of unreachable evacuation facilities	848	783	666	1,061	1,410	2,145
Rate of unreachable evacuation facilities	38.8%	99.9%	78.7%	100.0%	41.3%	100.0%
Number of delay occurrences	1,240	0	96	0	1,599	0
Rate of delay occurrences	56.7%	0.0%	11.3%	0.0%	46.8%	0.0%

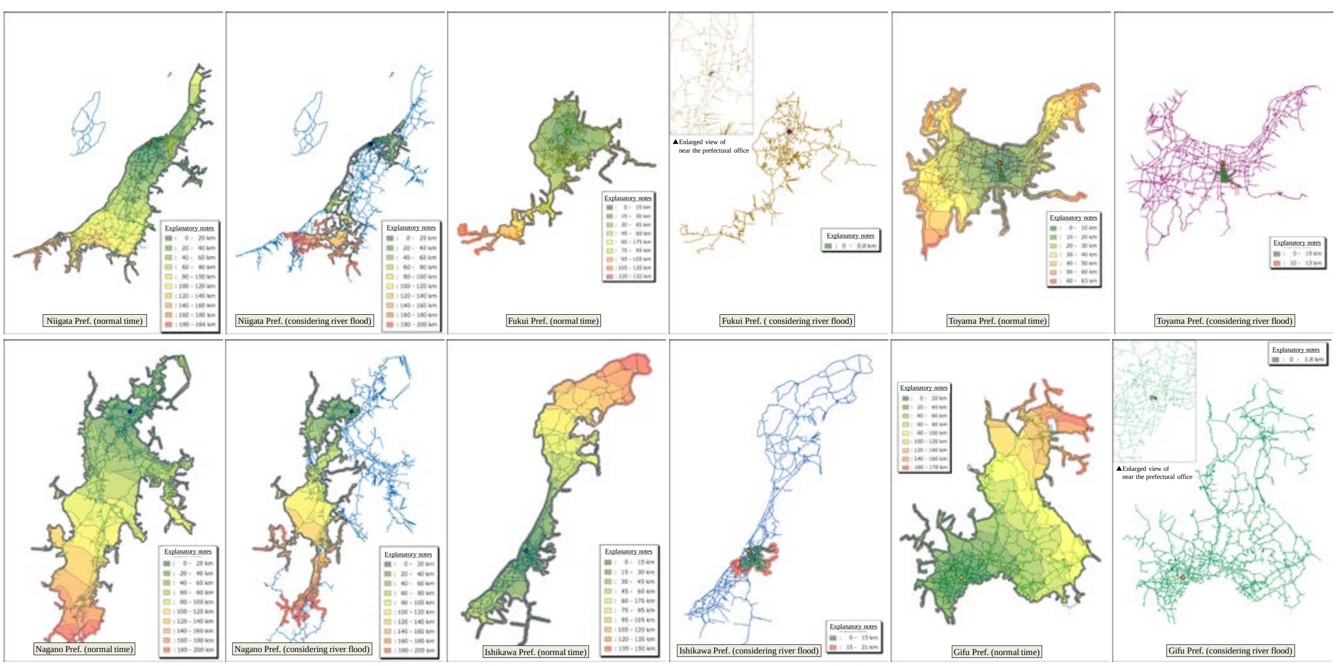

Fig.7 – Figure of reachable area from prefectural office in each prefecture (considering the river flood)

3.3 Reachability analysis between prefectural office and evacuation facilities considering collapse of roadside buildings caused by earthquake

In this study, distribution of instrumental seismic intensity by Japan Meteorological Agency (JMA) for a 2% probability of exceedance within 50 years (Fig 8) of the probabilistic seismic hazard maps published by *Japan Seismic Hazard Information Station* is used as design earthquake. Moreover, the fragility curve shown in damage assumption of Tokyo by The Great Nankai Trough Earthquake [8] (Fig 9 and Fig 10) is applied as damage function of buildings. Note that the fragility curve used for analysis is only the curve shown by the border in Fig 9 and Fig 10 owing to assumption of age of the building. The probability of complete destruction of each building are given by the method above and mentioned in 2.3. Next, it is conducted the complete destruction judgment of each building by random number simulation. In this simulation, to generate a 0.1 increments of random numbers in the range from 0 to 100, moreover, if the generated number is less than the probability of the complete destruction of the building, the building is completely destroyed and to impassable adjustment emergency transportation road. In, addition, in this study puts the focus on the development of analytical methods, the simulation is performed tentatively only at once.

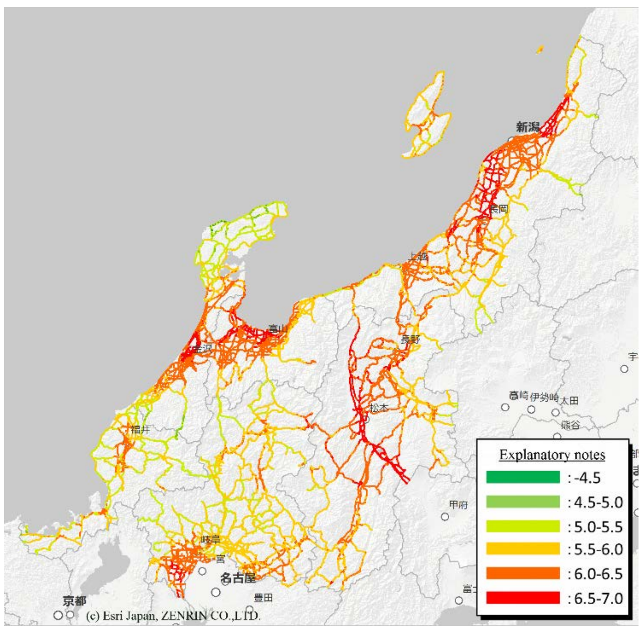

Fig.8 – Distribution of instrumental seismic intensity by JMA for a 2% probability of exceedance within 50 years

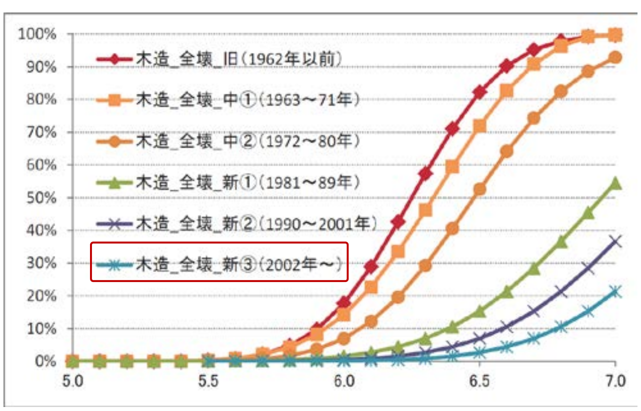

Fig.9 – Fragility curve of non-wooden building

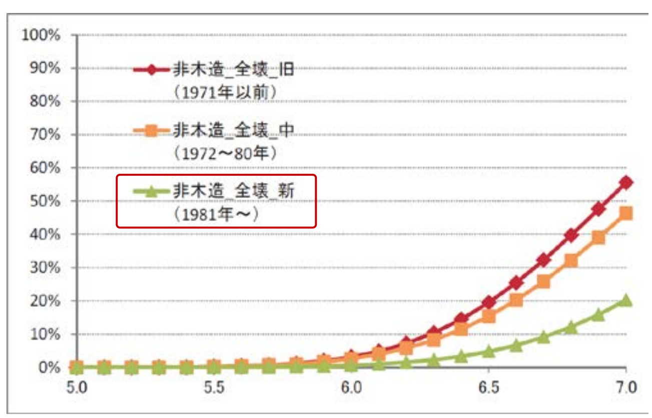

Fig.10 – Fragility curve of wooden building

The emergency transportation road network considering the road blockage caused by the road side building collapse is shown in Fig 11. The reachable area from prefectural office considering the road side building collapse caused by earthquake is shown in Fig 12. The result of the reachability analysis is presented in Table 6. As can be seen form Fig 7, there are many emergency transportation roads that anticipated high instrumental seismic intensity by JMA. In Niigata prefecture and Nagano prefecture, it is high risk of road blockage caused by road side building collapse in such a road. Namely if sparse parts of the network are such a road, it is necessary to caution as a vulnerable part. In these prefectures, it is found that actually unreachable area occurs owing to impassable of vulnerable part is shown in Fig 12. On the other hand, if there are many emergency transportation roads that anticipated high instrumental seismic intensity by JMA, provided that such roads exist in dense part of network, there is a chance that can be replace by other road. However, if the road blockage occurs on the shortest route from the prefectural office to evacuation facilities, delays occur. In order to rapid deal with disaster, it is important to understand the road which has high road blockage risk.

Table 6 – Result of reachability analysis in case of considering the building collapse

Prefectures	Niigata Pref.	Toyama Pref.	Ishikawa Pref.	Fukui Pref.	Nagano Pref.	Gifu Pref.
Number of subject of evacuation facilities	2,856	1,197	1,022	1,509	3,822	2,906
Number of unreachable evacuation facilities	209	116	75	86	586	65
Rate of unreachable evacuation facilities	7.3%	9.7%	7.3%	5.7%	15.3%	2.2%
Number of delay occurrences	463	423	128	5	1,015	376
Rate of delay occurrences	16.2%	35.3%	12.5%	0.3%	26.6%	12.9%

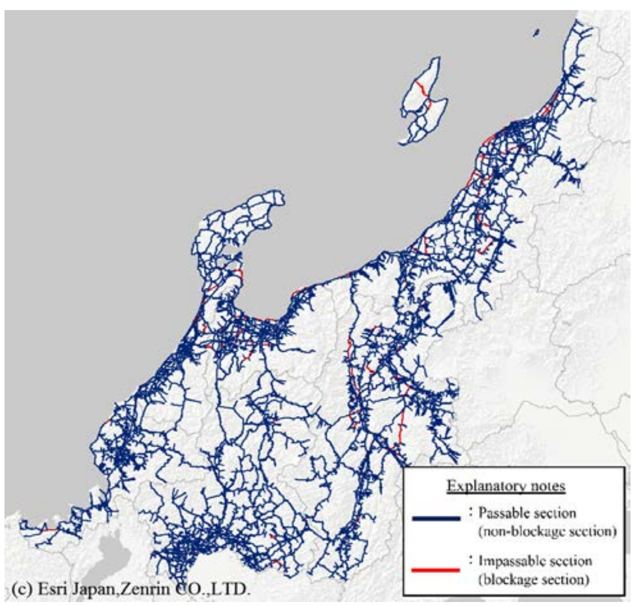

Fig.11 – Figure of emergency transportation road network considering the building collapse

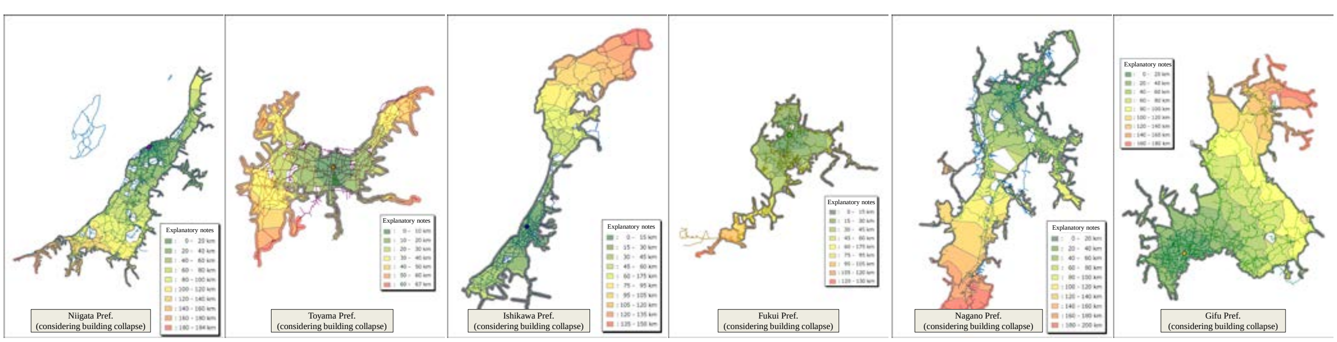

Fig.12 – Figure of reachable area from prefectural office in each prefecture (considering the building collapse)

3.4 Reachability analysis between prefectural office and evacuation facilities considering sediment disaster

Road sections that is likely to blockage caused by sediment disaster and emergency transportation road network considering this is presented in Fig. 13. The result of reachability analysis is shown in Table 7. Fig 14 is presented the reachable area from prefectural office considering sediment disaster. As can be seen from Fig 14 and Table 7, Since there are many mountains in Japan, many disaster risks of sediment disaster exist on emergency transportation road in mountains areas. Moreover, Occurrence of isolated areas is worried, owing to road network in such areas is often vulnerable. For example, in Nagano prefecture, around the prefectural office has been surrounded by mountains, there is a possibility of isolated as shown in Fig 14. Development of alternate road and implementation of sediment disaster measures of emergency transportation road is important.

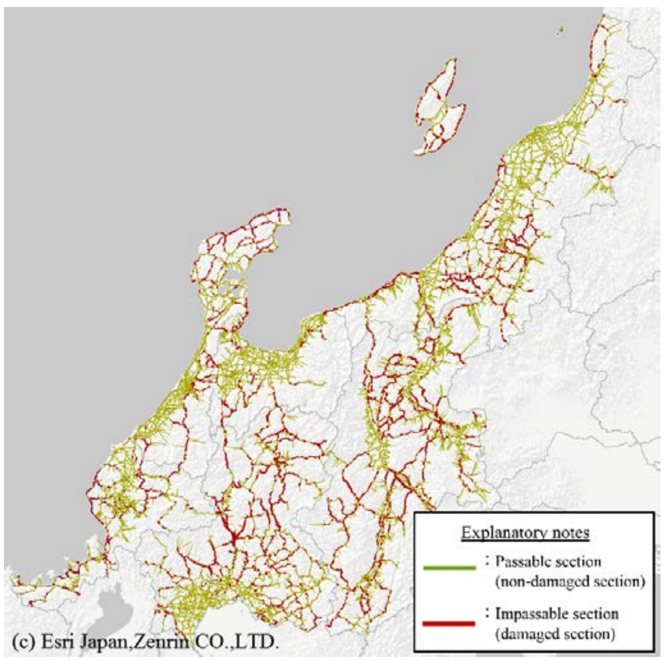

Fig.13 – Figure of emergency transportation road network considering the sediment disaster

Table 7 – Result of reachability analysis in case of considering the sediment disaster

Prefectures	Niigata Pref.	Toyama Pref.	Ishikawa Pref.	Fukui Pref.	Nagano Pref.	Gifu Pref.
Number of subject of evacuation facilities	2,853	1,197	1,022	1,509	3,822	2,906
Number of unreachable evacuation facilities	1,761	282	440	960	3,596	1,170
Rate of unreachable evacuation facilities	61.7%	23.6%	43.1%	63.6%	94.1%	60.9%
Number of delay occurrences	170	328	90	153	3	312
Rate of delay occurrences	6.0%	27.4%	8.8%	10.1%	0.1%	10.7%

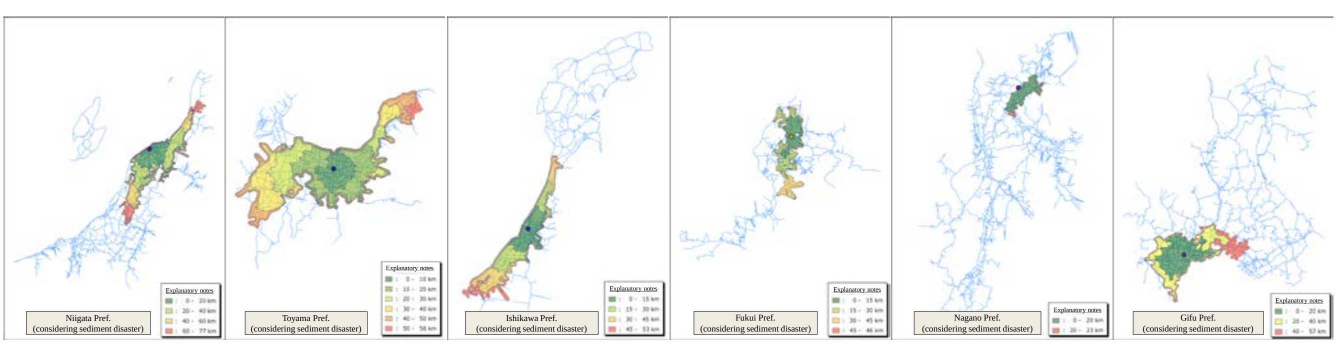

Fig.12 – Figure of reachable area from prefectural office in each prefecture (considering the sediment disaster)

3.5 Reachability analysis between prefectural office and evacuation facilities considering complex disaster

In case of considering the complex disaster, complex case of river flood and earthquake, earthquake and sediment disaster, river flood and sediment disaster are analyzed. Due to limited space, only exhibit the complex case of earthquake and sediment disaster in this paper. In cases of complex disaster, it is considered that damages caused by each disaster are occurred at the same time. Namely, it is conceived the network considering all impassable sections in each disaster case. Emergency transportation road network in case of complex disaster is presented in Fig 15. The result of reachability analysis is shown in Table 8. Fig 15 is presented the reachable area from prefectural office considering complex disaster. On the whole, impact of sediment disaster is predominant. Impact of sediment disaster is concentrated in mountains areas. On the other hand, impact of building collapse is concentrated in urban area. Therefore, as can be seen from Fig 16, it is considered the possibility of overlap of damages is low. However, it is suggested the possibility that damages of target areas are over a wide range, it is necessary to sufficiently vigilance.

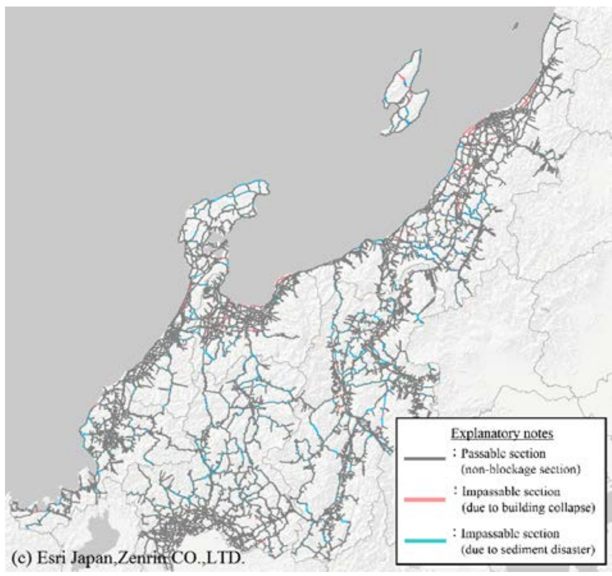

Fig.15 – Figure of emergency transportation road network considering the earthquake and sediment disaster

Table 7 – Result of reachability analysis in case of considering the earthquake and sediment disaster

Prefectures	Niigata Pref.	Toyama Pref.	Ishikawa Pref.	Fukui Pref.	Nagano Pref.	Gifu Pref.
Number of subject of evacuation facilities	2,853	1,197	1,022	1,509	3,822	2,906
Number of unreachable evacuation facilities	1,870	374	484	974	3,623	1,808
Rate of unreachable evacuation facilities	65.5%	31.2%	47.4%	64.5%	94.8%	62.2%
Number of delay occurrences	361	560	156	153	2	591
Rate of delay occurrences	12.7%	46.8%	15.3%	10.1%	0.1%	20.3%

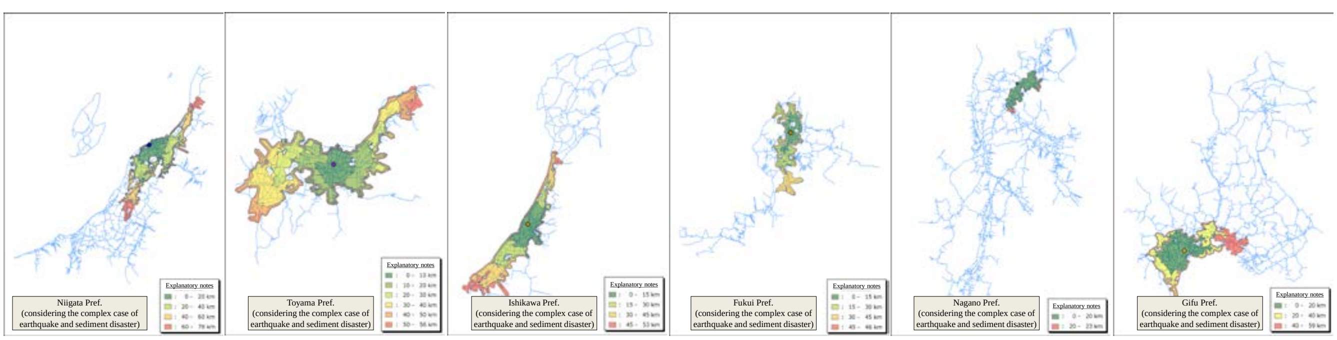

Fig.16 – Figure of reachable area from prefectural office in each prefecture (considering the earthqkake and sediment disaster)

4. Conclusions

In this paper, it is analysed the possibility of disaster risk considering the road flooding caused by river flood, road blockage caused by building collapse, road blockage of sediment disaster, and complex cases of each disaster. On the basis of this analysis result, it is analysed the reachability between prefectural office and evacuation facilities that targeted Niigata prefecture, Toyama prefecture, Ishikawa prefecture, Fukui Prefecture, Nagano prefecture and Gifu prefecture.

In analysis of impact of river flood, it is suggested the possibility that there are many dangerous site on emergency transportation road. On the other hand, the possibility that all flood-assumed areas that flood-depth is 0.5 meters or more are flooding at the same time is low, it is necessary to refine the analytical method.

In analysis of impact of building collapse caused by earthquake, it is suggested possibility that the unreachable area is occurred when building collapse happened in vulnerable parts of the network. In future research, it will consider to elements other than building collapse as an impact of earthquake, while at the same time refining the analytical method of building collapse.

In analysis of impact of sediment disaster, due to the influence of sediment disasters is consistent with structurally vulnerable places in the network, it showed the possibility that the isolated areas are occurred. In future research, it will refine the analytical method such as to assess the presence or absence of sediment disaster stochastically.

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