Road priority evaluation for seismic survivability by user cost and redundancy

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SUMMARY:
This research proposed a method of judging the order of priority of the road using a combination of redundancy of the road and user benefit. User benefit indicates the degree of contribution of the road to social or economic activity. On the other hand, redundancy is an indicator of showing the fullness of the detour to object road. This can evaluate the risk of isolation at the time of a disaster. A redundancy of a road was computed as the minimum length of detour when the target road is closed. The proposed method was applied to one local region, Shimane Prefecture in Japan. A network model of traffic simulation was applied to roads in this region. User benefit and a redundancy were calculated from the traffic simulation. The order of priority computed from these indices was in agreement with the tendency recognized experientially, confirming the validity of the proposal method.

Keywords: Road, redundancy, seismic survivability

1. INTORODUCTION

In a catastrophic seismic event such as the Tohoku Earthquake, many roads are closed simultaneously. Since many localities are isolated, it is very difficult to carry out support action such as speedy investigation of the disaster, prompt rescue of victims and effective delivery of aid. Therefore, by performing brittle-evaluation of a road route at the disaster, it is necessary to clarify beforehand the route which has big influence when that route is stopped.

Here, although the brittleness of a road is greatly influenced by the safety factor of individual points on the road, such as slope failure, existence of an alternative route is also a great factor to secure traffic flow at the time of disaster. In this problem, it is necessary to treat each road as a part of road network. However, since the road network is extensive, it is difficult to improve the seismic survivability of all roads due to budget limitations. Thus, a method is needed to determine the order of priority of seismic survivability of a road.

This research evaluates a value of the road route value, by existence of alternative routes (redundancy) and the influence which the road route plays in a social activity. The influence which it has on the social activity of a road route is calculated as user cost which is the convenience that a existence of the road brought to a user. This research examines the value of national roads in Shimane prefecture, using a traffic simulation.

2. VALUE EVALUATION TECHNIQUE OF A ROAD ROUTE

In this study, the influence of road routes to social activity is evaluated by user cost. User cost is a benefit brought to a road user by a presence of road route, and is taken as the sum of two benefits. One is the benefit getting from reduction of travel time and the other is the benefit that is provided from reduction of travel costs. A road route is modeled by a network model, a traffic simulation is performed using this model, and a traffic situation is reproduced by equilibrium assignment algorithm.

In this algorithm, traffic of one day of an object route is divide into n (usually n=4 to 10). At each division, the shortest time path from origin node i to destination node j was found by using relationship between traffic volume and velocity (Q-V curve). The traffic which was divided is applied to all the links included in the selected route. By repeating these work n times, it becomes an alternative path when an object route is closed.

By a traffic simulation, differences of the trip time and the mileage between normal situation and the case of block would be calculated. User costs are computed by multiplying the each difference by each standard unit.

A benefit getting from reduction of travel time b_t:

$$b_t = \alpha \sum_{i=1}^{m} \sum_{j=1}^{m} \left\{ \sum_{h=1}^{n} \left(q'_{hij}\, t'_{hij} \right) - q_{ij}\, t_{ij} \right\} \tag{2.1}$$

Where, α: Time value standard unit (yen/hour), q'_{hij}: Traffic volume between node i-j in the h-th number of times of distribution at the time of object route section stoppage (car/one side/day), t'_{hij}: Travel time between node i-j in the h-th number of times of distribution at the time of object route section stoppage (hour), q'_{ij}: Traffic volume between node i-j under normal situation(car/one side/day), t_{ij}: Travel time between node i-j under normal situation (hour), n :Number of allocation, m : Number of nodes.

A benefit getting from reduction of travel cost b_m:

$$b_m = \beta \sum_{i=1}^{m} \sum_{j=1}^{m} \{ \sum_{h=1}^{n} (q'_{hij} l'_{hij}) - q_{ij} l_{ij})\} \tag{2.2}$$

Where, β: Drive cost standard unit (yen/km), l'_{hij}: Travel distance between node i-j in the h-th number of times of distribution at the time of object route section stoppage (km), l_{ij}: Travel distance between node i-j in the h-th number of times of distribution under normal situation (km)

Here, referring from the cost-benefit analysis manual of the Japan Ministry of Land, Infrastructure, Transport and Tourism, it is assumed that time value standard unit is 2406 (yen/hour/car) and driving cost standard unit is set to 9-29 (yen/km) according to speed. When an object route is blocked, it searches for the route which can detour in shortest time. At this time, traffics are distributed by Traffic Assignment Methods; travel speed is computed by the Q-V curve which is set up by this research. Network models of Yamaguchi Prefecture and Shimane Prefecture which are used in this research are shown in Fig.2 and Fig.3.

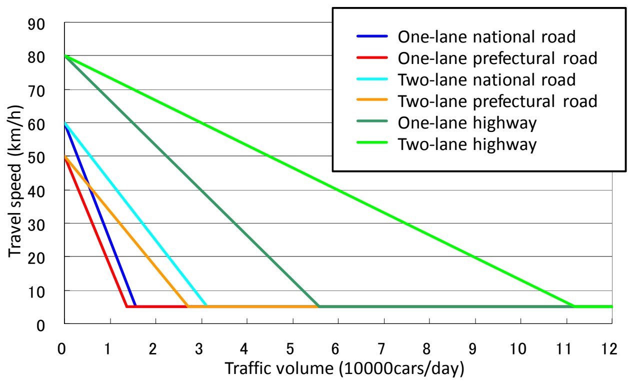

Figure 1. Q-V curve

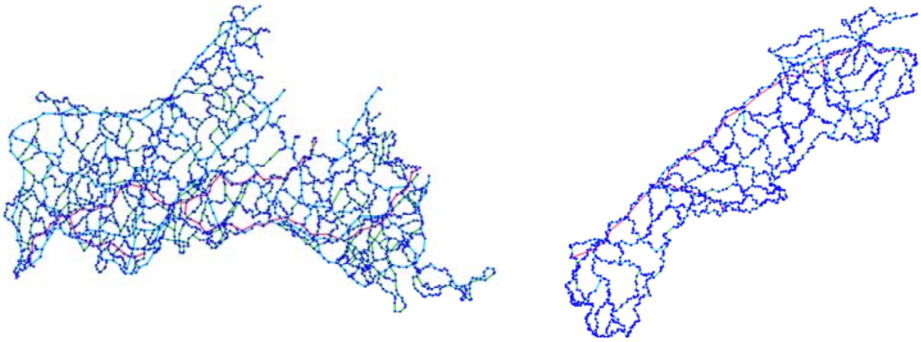

Figure 2. Network models of Yamaguchi Prefecture and Shimane Prefecture

Figure 3 shows an example of traffic simulation. In July 21 2009, many roads in Yamaguchi prefecture including trunk roads were stopped according to sediment disaster due to heavy rain. Most traffic detours widely to the west side, Route 9 and Route 2 are used as a detour. Result of this simulation is well in agreement with the phenomenon which actually occurred. Since traffic capacity of Route2 is smaller than traffic volume of blocked route, chronic traffic congestion had occurred. As seen above, when a catastrophic disaster occurs, road traffic is damaged by large detour and traffic congestion. In order to evaluate the importance of a road for save of the lifeline at the time of a disaster, it is important to regard not as a single route but as a road network.

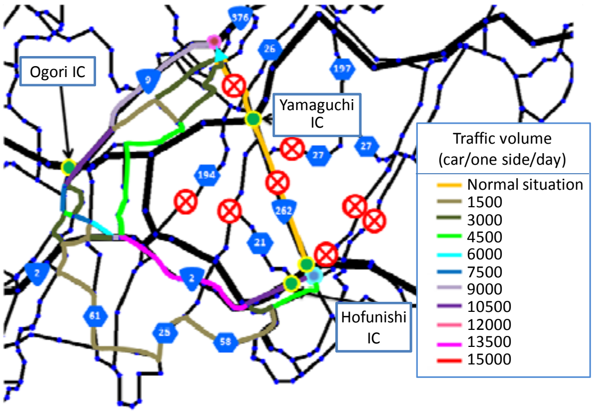

Figure 3. Network models of Yamaguchi Prefecture and Shimane Prefecture

3. THE ROAD VALUE EVALUATION

The traffic simulation of Shimane Prefecture was performed. National highways were targeted in this simulation. In this analysis, routes from a city to a city are made into object routes, and between main crossings are identified as one route. Moreover, a border between prefectures with a neighboring prefecture shall be dealt with as a route equivalent to a principal prefectural road, and it shall be used as a detour.

As an example, Fig.4 shows the detour routes and distribution traffic at the time of route *cc* stoppage. When the route *cc* is blocked, it turns out that the traffic in an object route is distributed to the surrounding route network. At the time of stoppage of the route *cc*, the average trip time is 106 minutes and average roundabout mileage is 58.3 km. In the normal situation, the average trip time is 53 minutes and average trip mileage is 28.4 km, so 53 minutes and 29.9 km become increment due to road blocked. In other words, existence of route *cc* could provide 53 minutes and reduce trip cost for 29.9km. User cost is computed by converting into monetary value the running time and run expenses which were cut down, so amount of user cost of route *cc* is 34,100,000 yen / one side / day.

The user costs of national roads in Shimane prefecture were computed, Fig.5 indicates user costs that is classified by color on the network model. The most valuable route is route *dd*, that user cost is

135,470,000 yen / one side / day, second is route *cc* with 34,100,000 yen / one side / day and third is route *p* with 30,700,000 yen / one side / day. The user cost of route dd exceeded 100 million yen, and it has taken the very big value. The reason why is route *dd* has very large amount of traffics 19270 cars / one side / day, and the length of detour route is long as 67.8 km. User cost is strongly dependent on traffic volume, and user cost becomes high on a heavy-trafficked route.

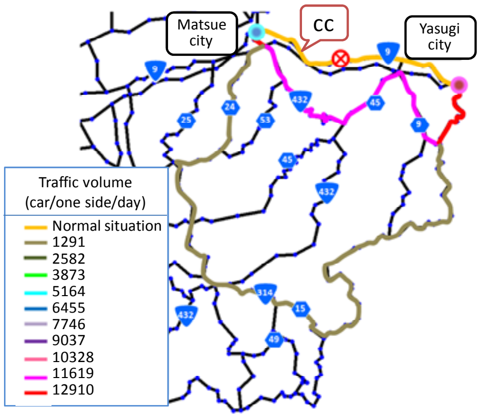

Figure 4. Detour routes and distribution of traffic with route cc stoppage

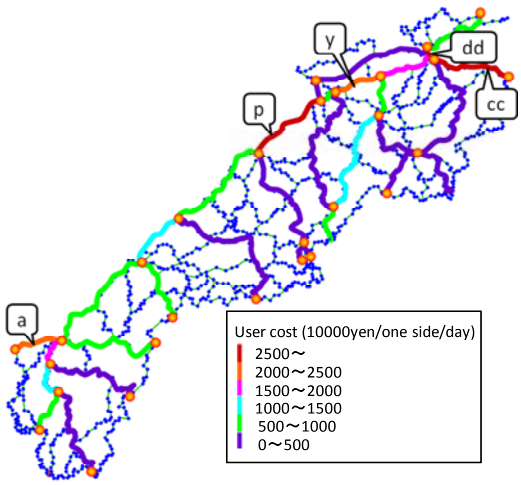

Figure 5. User cost

On the other hand, compared with major-cities like Izumo and Matsue, there are thinly distributed road networks near the mountain area. Although there is little traffic on the road of such an area, a large detour is needed when moving between cities, if a route is closed. Therefore, it should be considered that the road value evaluation only by user cost is not adapted to such low density road-network area. Then, in order to evaluate all the road routes in Shimane comprehensively, other index is needed.

Therefore, redundancy of a road network is considered in addition to user cost. This way could evaluate not only road value under normal situation but also survivability of transportation under shiver hazard. User cost and travel distance under blocked condition differs from these under normal situation.

The vertical axis of Fig.6 is a rate of change of a user defrayment which is computed by dividing the difference of the user cost by the user cost at the time of normal situation. Rate of change of a user defrayment is computed by Eq.(1).

$$u_{br} = \frac{u_c' - u_c}{u_c} \tag{3.1}$$

Where, u_{br} : Rate of change of a user defrayment, u_c : user defrayment under normal situation, u'_c : user defrayment under blocked situation.
The horizontal axis of Fig.6 has calculated by dividing the increase in travel distance by original road length.

$$\ell_r = \sum_{i=1}^{m}\sum_{j=1}^{m}\left(\frac{\frac{1}{n}\sum_{r=1}^{n}\left(v'_{rij}t'_{rij}\right) - v_{ij}t_{ij}}{v_{ij}t_{ij}}\right) \tag{3.2}$$

Where, v_{ij} : trip velocity under normal situation, t_{ij} : trip time under normal situation, v'_{ij} : trip velocity when the road is blocked, t'_{ij} : trip time when the road is blocked.

The concentric circles are drawn into Fig. 6. From a viewpoint of economical efficiency and redundancy, important routes are placed far from origin. In Fig.6, route *a* and route *r* are pointed around the most outer circle.

Traffic volume of route *a* is 5840 set / one side / day and that of route *r* is 2850 set / one side / day, in comparison with that of route dd whose user cost was the highest in this region, it is very small. Thus, this method could evaluate the route which has low user cost due to low traffics.

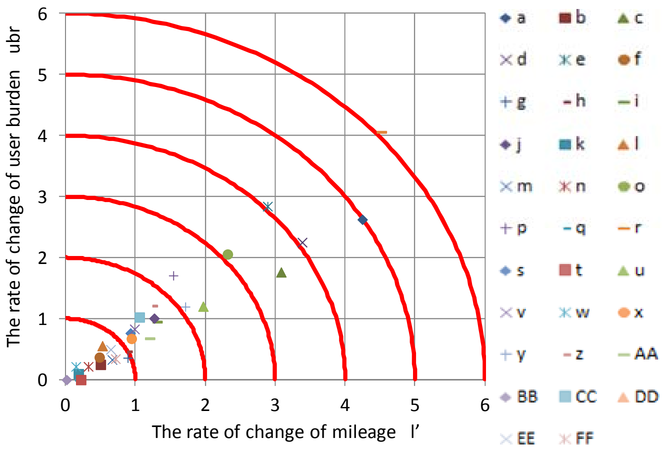

Figure 6. New evaluation method

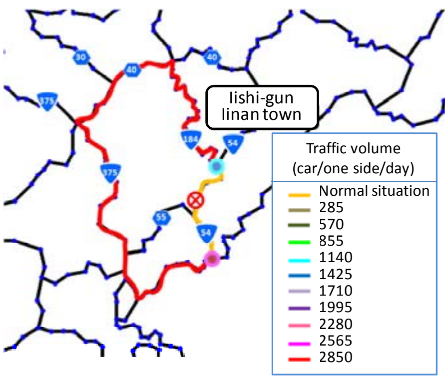

Figure 7. Detour routes and distribution of traffic with route r stoppage

Detail of route *r* which was estimated to be the most important by the index of Fig.5 is as follows. Distribution of detour routes and distribution of traffic flow are shown in Fig.7, at the time of the route *r* being blocked. Under the normal condition, traffic volume of route *r* is 2850 cars / one side / day, travel speed is 46.2 km/h and section length is 12.5 km. As shown in Fig.7, since there are few detours, the large detour is carried out. The length of the detour of this route is 69.0 km, and must drive the distance of 5 times or more compared with usual route. Moreover, while the usual trip time is 16 minutes, the trip time of detour became 81 minutes. Such as this route that has few detours due to low redundancy of road network, it is concerned that these colonies will be isolated at the time of natural hazard. The proposed index can turn into the road land-assessments value evaluation index that user cost and redundancy can be evaluated synthetically.

4. CONCLUSINON

User cost is strongly dependent on traffic volume. Therefore, in evaluation of only user cost, it is difficult to evaluate the road route which has few detours and low traffic volume. This paper proposes a new method to evaluate road value by not only user cost but also redundancy of road route. This technique could be adapted to safety assessment of road under disaster.

In preparation for a catastrophic natural disaster, it also becomes important to consider the benefit under the disaster to cost-benefit analysis in addition to user cost. The information acquired by this research not only turns into the management techniques, such as determination, repair cost allocation, etc. of a maintenance repair priority, and useful information for an infrastructure building strategy, but can become evasion of the isolation at the time of a disaster, and an index for reservation of a lifeline.

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