**This document presents an example of our proposed algorithm for designing geographical routes.**

## I. Inputs

1) Network information

Locations of network nodes: (lat, lon)

- Node 1 : (34.440477, 132.407913),
- Node 2 : (34.460295, 133.189316),
- Node 3 : (34.676285, 133.821029),
- Node 4 : (34.850024, 134.730148),
- Node 5 : (35.542432, 134.813919),
- Node 6 : (35.516727, 134.191818),
- Node 7 : (35.384720, 132.892685),
- Node 8 : (34.899597, 132.112655),

Nodes 1-2-3-4-5-6-7-8 and 3-6 are connected (see Fig.1).

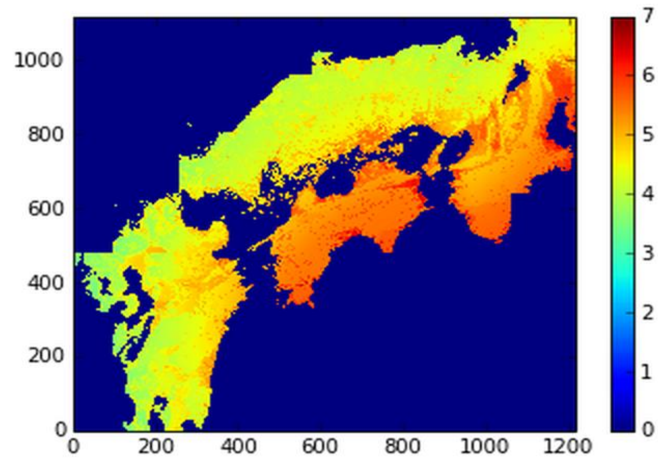
Note that these node locations and the network topology may be artificial.

2) Considered earthquakes: 5 earthquakes from J-SHIS given in http://www.j-shis.bosai.go.jp/map/JSHIS2/download.html?lang=en

- Huge earthquake: ANNKI/MAP/C-V2-ANN21-MAP-CASE1.csv
- Local earthquake 1: F010601/MAP/C-V2-F010601-MAP-CASE1.csv
- Local earthquake 2: F010701/MAP/C-V2-F010701-MAP-CASE1.csv
- Local earthquake 3: F008001/MAP/C-V2-F008001-MAP-CASE1.csv
- Local earthquake 4: F008106/MAP/C-V2-F008106-MAP-CASE1.csv

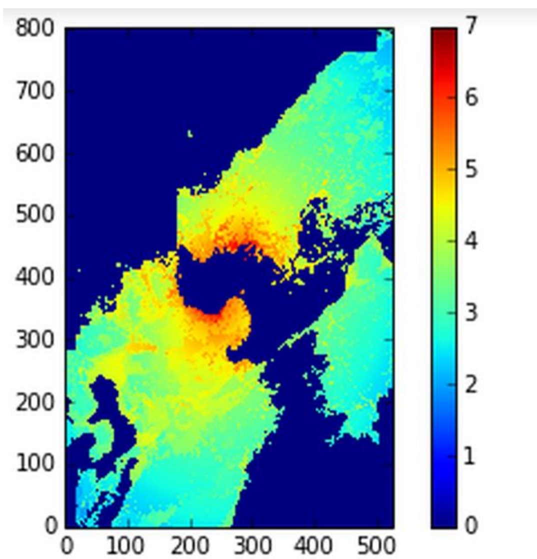
A method downloading these data sets are shown in Appendix.

The hazard maps of these earthquakes are visualized in the following figures:



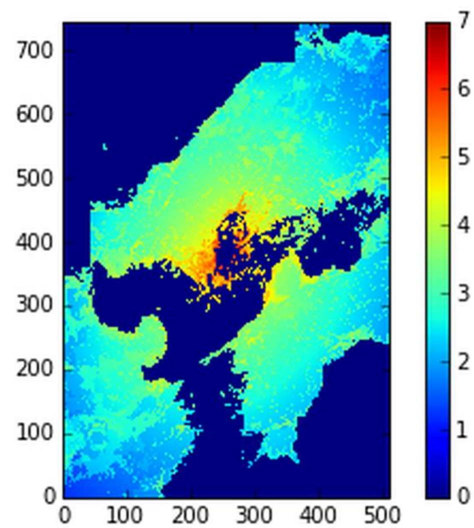

Nankai Trough earthquakes (YXEs))

Huge Earthquake



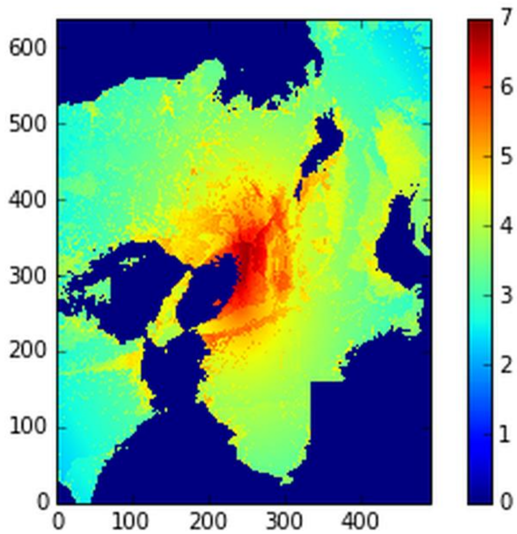

Suonada fault group (Main part)

Local earthquake 1



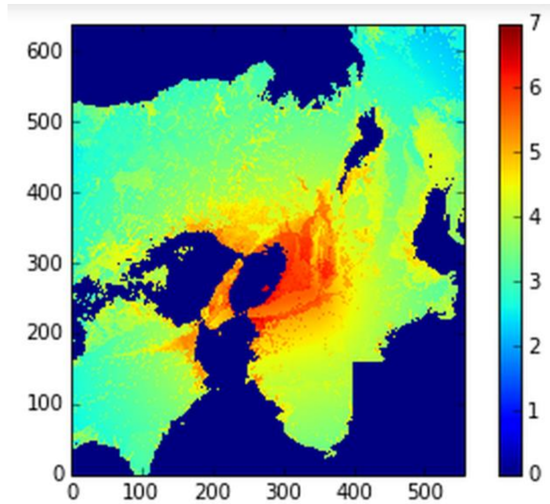

Akinada fault group (Main part)

Local earthquake 2




Uemachi fault zone

Local earthquake 3




Chuo-kozosen fault zone (Izumi-sanmyaku-nanen)

Local earthquake 4

3) Street map

The geographical street map is obtained from the OSM (https://www.openstreetmap.org). We took only routes with the highway tag in {motorway, trunk, primary, secondary}. Other small routes were filtered out.

4) Parameter

We assume that all links in an area of earthquake intensity $\boldsymbol{I}$ have the same link failure rate $\beta_{\mathrm{I}}$ [1/km]; 0.05 for $\boldsymbol{I} \in [5; 5:5)$ on the Japanese scale of 7, 0.1 for $\boldsymbol{I} \in [5:5; 6:0)$, 0.12 for $\boldsymbol{I} \geq 6.0$, and 0 otherwise.

## II. Results

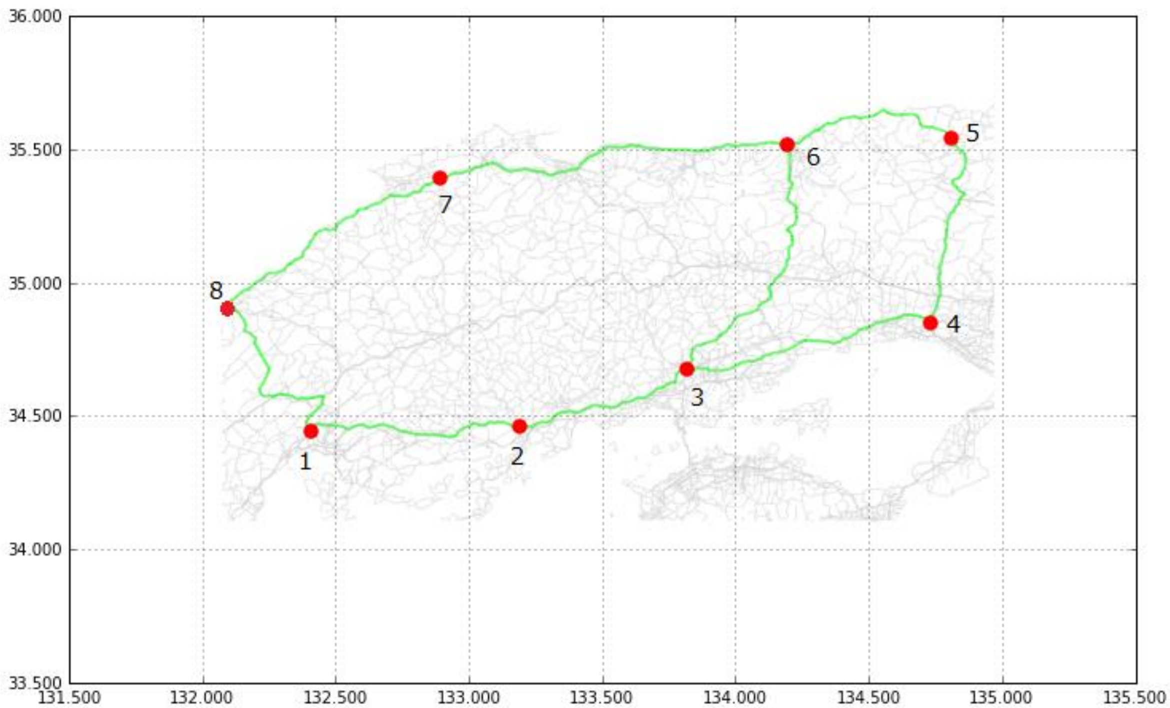



Fig 1. Shortest geographical routes.

Three out of 9 links have more than 1 Pareto solutions (1-2), (2-3) and (3-4). The following are the routes with route lengths and disconnection probabilities corresponding to each earthquake.

(Route length (km); HE; LE1; LE2; LE3; LE4)

Link (1-2)

（80.6; 62%; 2.6%; 1.4%; 0; 0）

（120.5; 65%; 0.15%; 2.1%, 0; 0）

（128.4; 55.5%; 0.15%; 1.7%; 0; 0）

Link (2-3)

（70.7; 91%; 0; 0; 0; 0.6%）

(120; 87%; 0; 0; 0; 2.6%)

(142; 85.6%; 0; 0; 0; 2.6%)

(153; 84%; 0; 0; 0; 2.6%)

(155.5; 81%; 0; 0; 0; 2.6%)

Link (3-4)

(98; 97.3%; 0; 0; 3.7%; 28%)

(132.5; 93.3%; 0; 0; 2.4%; 16%)

(138; 91.7%; 0; 0; 3.4%; 13%)

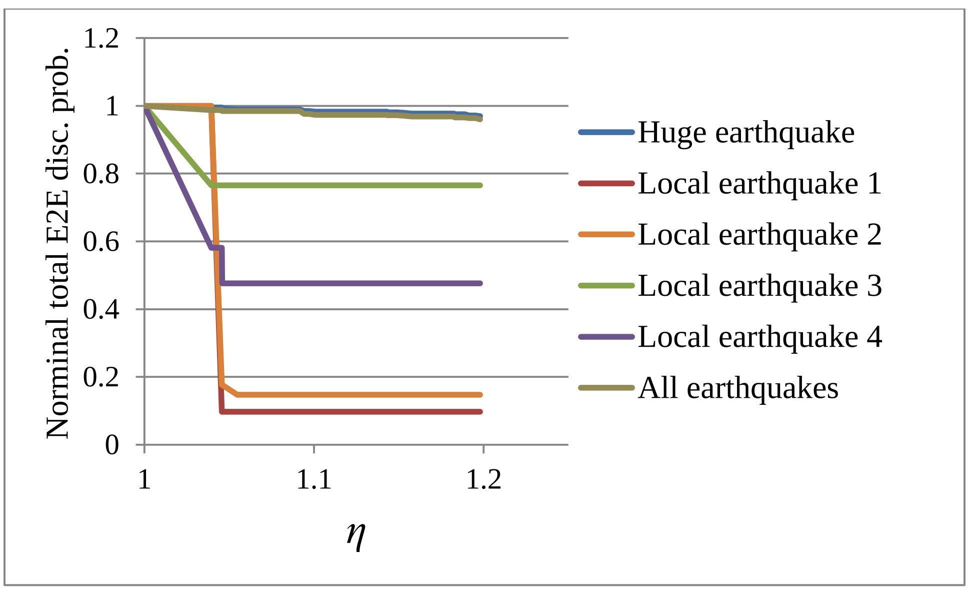



Fig 2. Performance gain for artificial nation-wide network

During local earthquake 1 & local earthquake 2, the end-to-end disconnection (E2E)probability could be significantly reduced with an alternative route. This is because a local earthquake is small and affects only one link. Hence, it is possible to find an alternative route that bypasses the earthquake-affected region. This route has the failure probability almost equal to zero. The total E2E disconnection probability is therefore significantly reduced.

For the huge earthquake, however, even though it is possible to find alternative routes that reduce the link failure probability by approx. 10%, the link failure probabilities of all network links are still quite high. Therefore, the relative reduction of total E2E probability is small (approx. 4%).

In this example, the huge earthquake affects the entire network. Consequently, the result when considering all earthquakes (with equal weights) is almost identical to that when considering the huge earthquake alone.

The following are graphs showing the optimal geographical routes considering each earthquake as well as all earthquakes with equal weights. The cost factor $\eta$ is set to 1.2.

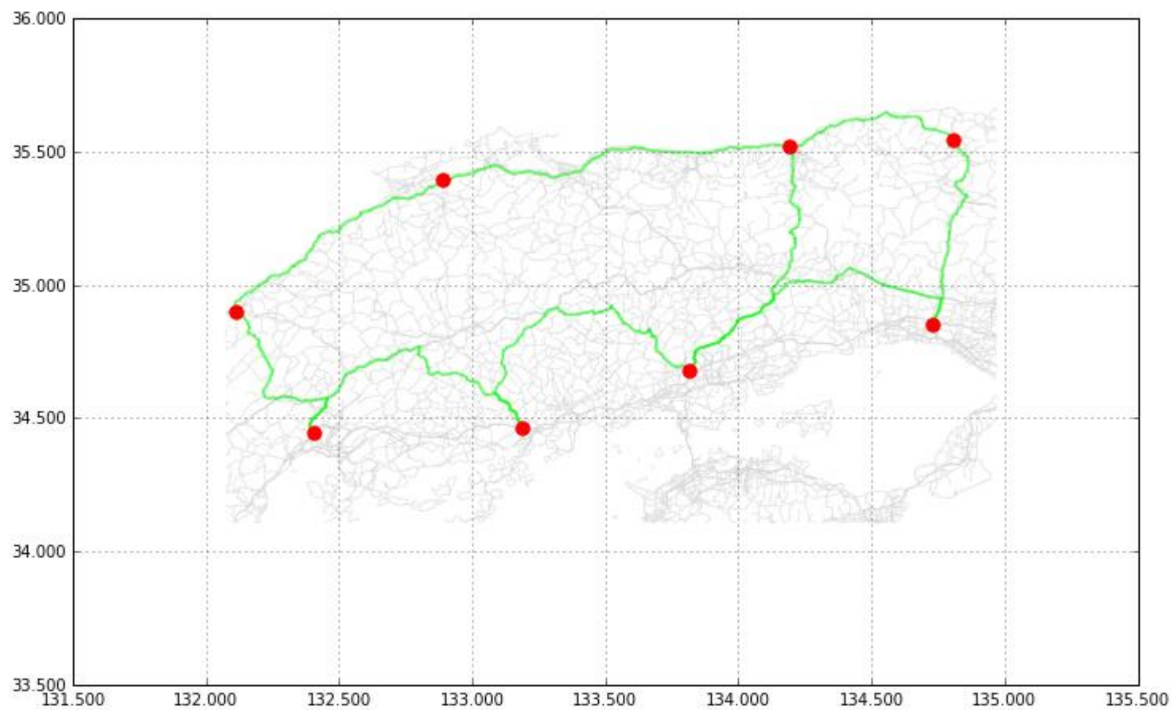



Fig. 3. Optimal geographical network during huge earthquake and all earthquakes

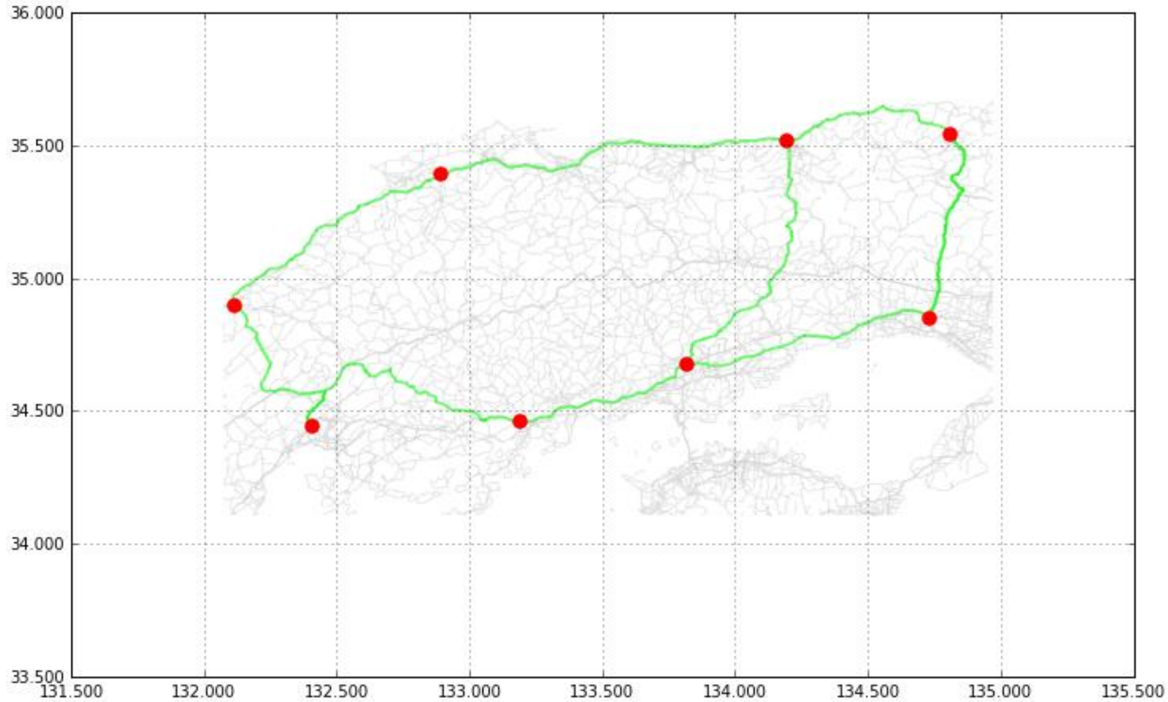



Fig. 4. Optimal geographical network during local earthquake 1

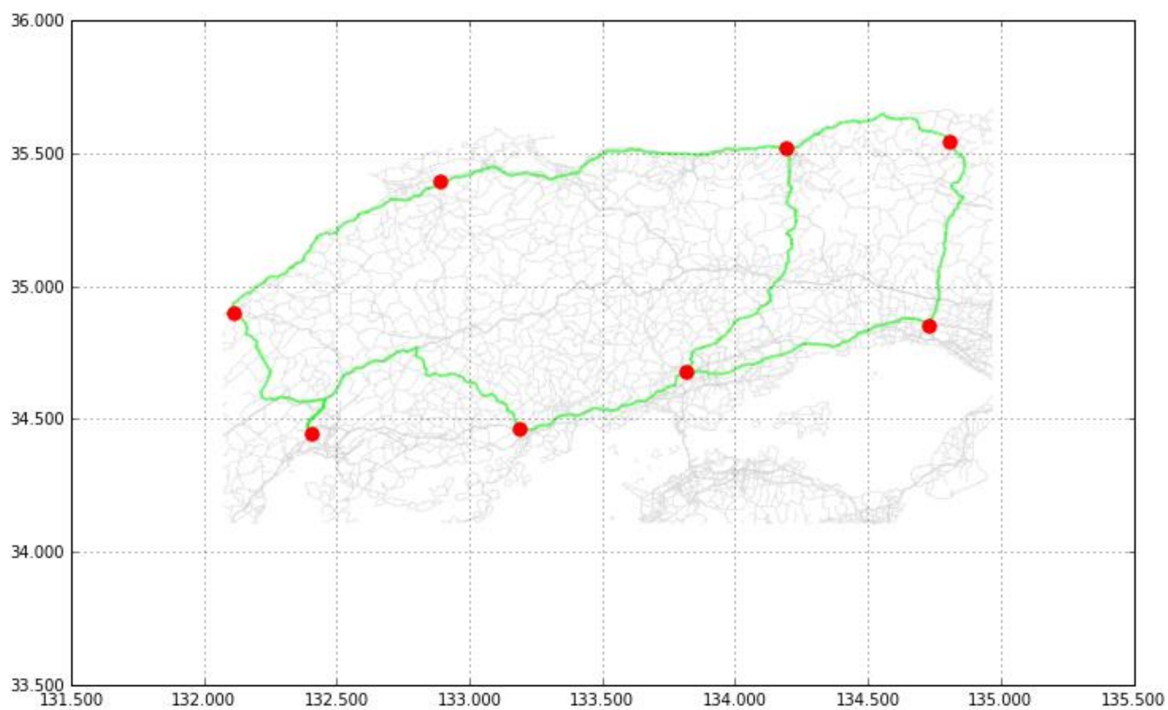



Fig. 5. Optimal geographical network during local earthquake 2

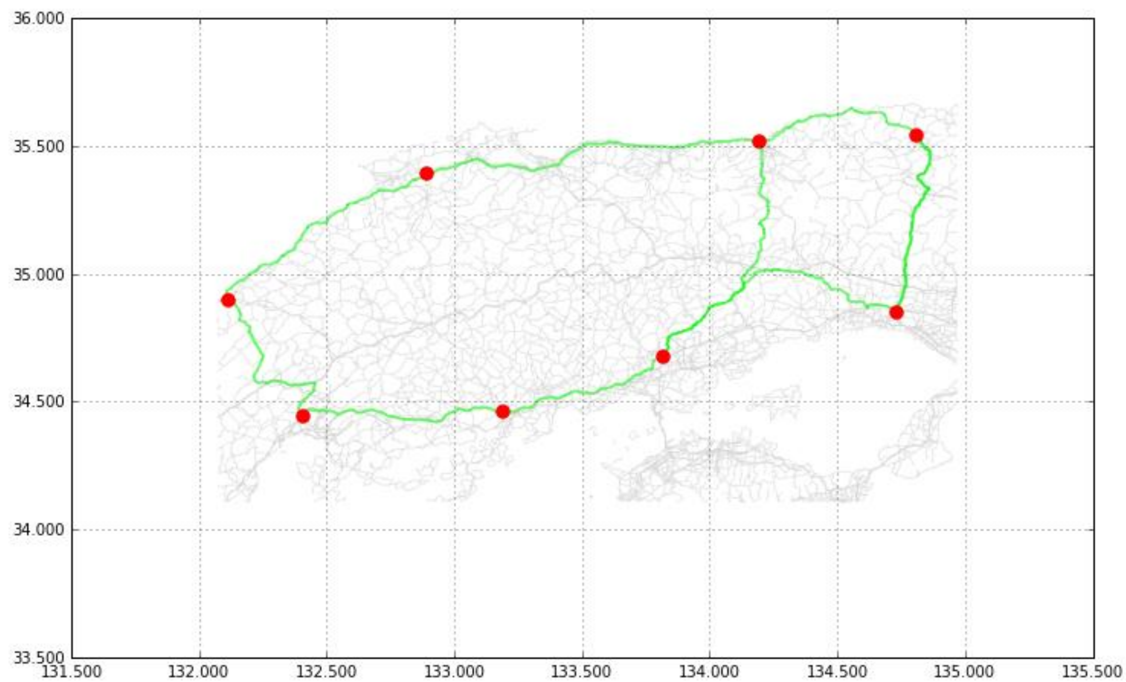



Fig. 6. Optimal geographical network during local earthquake 3

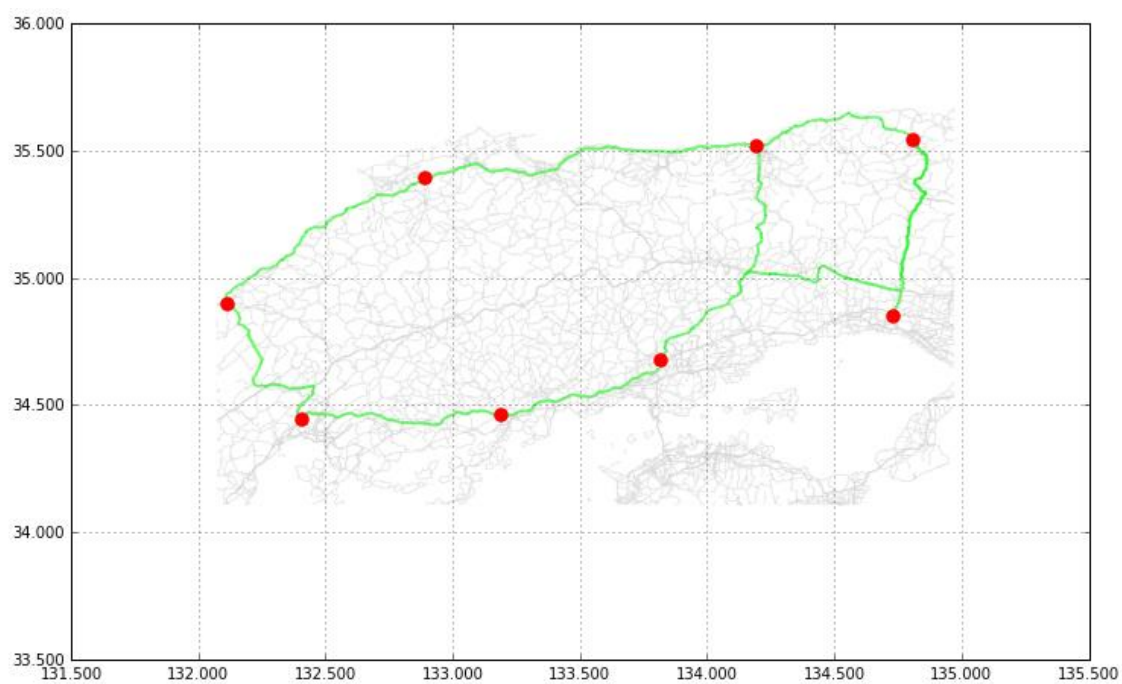



Fig. 7. Optimal geographical network during local earthquake 4

## Appendix

J-SHIS download page is shown below.

In Japanese: http://www.j-shis.bosai.go.jp/map/JSHIS2/download.html?lang=jp

In English: http://www.j-shis.bosai.go.jp/map/JSHIS2/download.html?lang=en

Download procedure

1. Data set: Choose Conditional Probability of Exceedance

2. Earthquake: Choose Subduction-Zone Earthquakes to obtain ANNKI/MAP/C-V2-ANN21-MAP-CASE1.csv, and Major Active Fault Zones to obtain other data sets.

3. Seismic source fault in the right column: Choose

Nankai Trough earthquakes (YXEs)) for ANNKI/MAP/C-V2-ANN21-MAP-CASE1.csv,

Suonada fault group (Main part) for F010601/MAP/C-V2-F010601-MAP-CASE1.csv,

Akinada fault group (Main part) for F010701/MAP/C-V2-F010701-MAP-CASE1.csv,

Uemachi fault zone for F008001/MAP/C-V2-F008001-MAP-CASE1.csv,

Chuo-kozosen fault zone (Izumi-sanmyaku-nanen) for F008106/MAP/C-V2-F008106-MAP-CASE1.csv.

4. Download

Additional information can be found at Japan Seismic Hazard Information Station (J-SHIS) File format specification

http://www.j-shis.bosai.go.jp/map/JSHIS2/data/DOC/DataFileRule/A-RULES_en.pdf