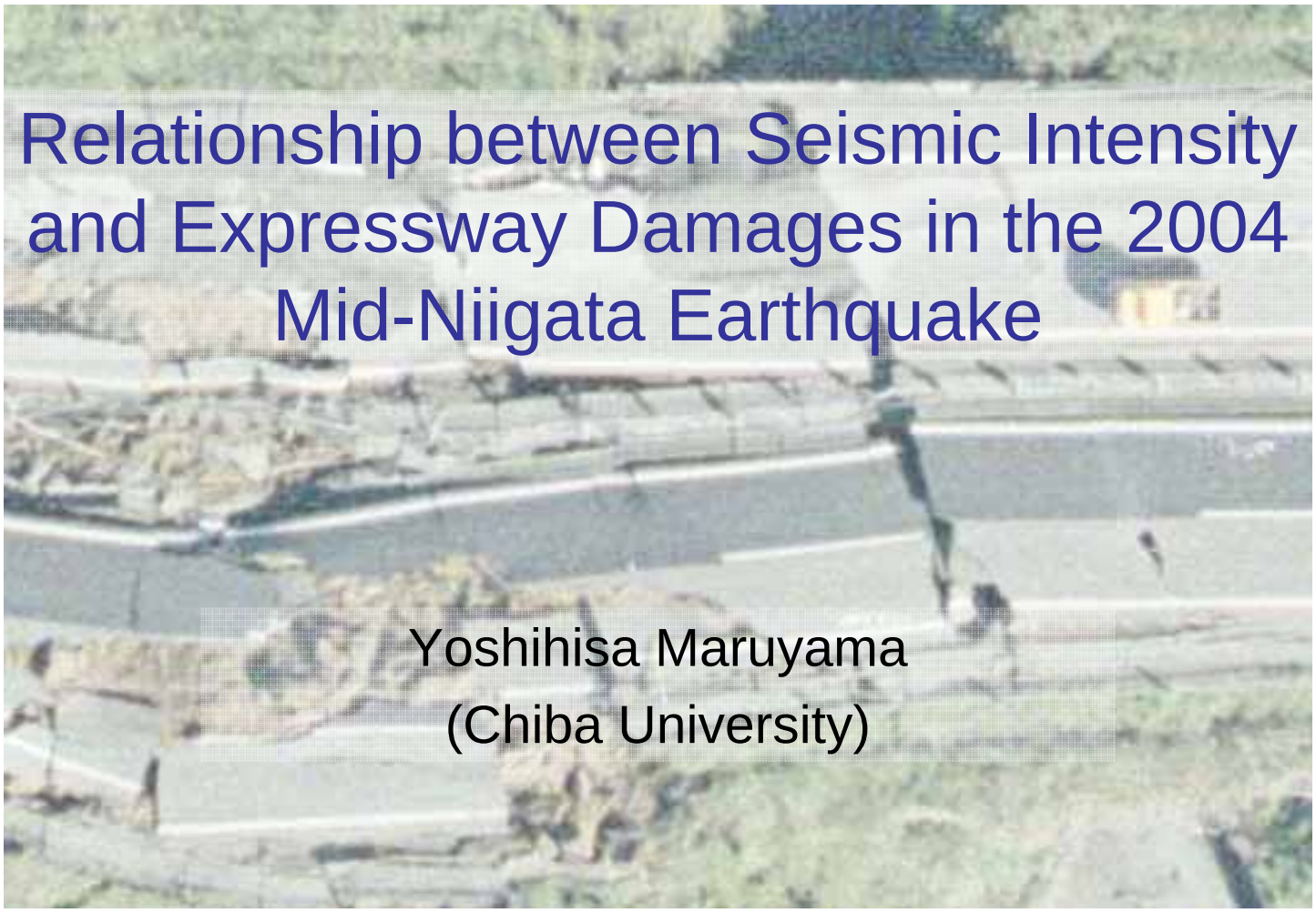


Relationship between Seismic Intensity and Expressway Damages in the 2004 Mid-Niigata Earthquake

Yoshihisa Maruyama
(Chiba University)

Introduction

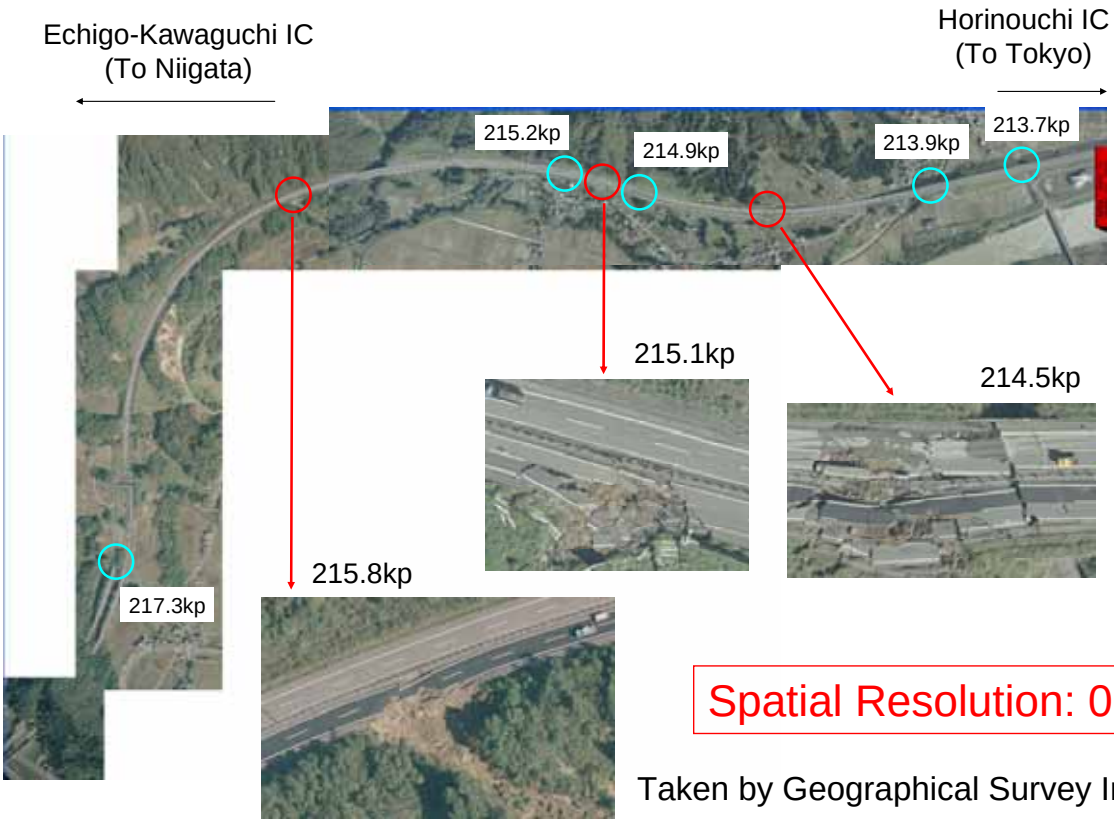
In the Mid Niigata earthquake, which occurred on October 23, 2004, the expressways were closed just after the earthquake. Many major and minor damages were caused because of this earthquake, especially for expressway embankments.

In order to support a rapid disaster response in the expressway network,

- Image processing of aerial photographs to identify the damaged sections of the expressways
- Relationship between the damage ratio of expressway embankment and seismic intensity to construct fragility curves.

1. Image Processing of Aerial Photographs to Detect the Expressway Damages

Expressway Damages Captured in Aerial Photographs



Spatial Resolution: 0.1 m

Taken by Geographical Survey Institute, Japan

Comparison of Damages Detected from the Aerial Photograph and Field Photographs


Aerial Photo

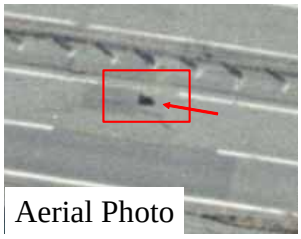

Field Photo

213.9 kp


Aerial Photo

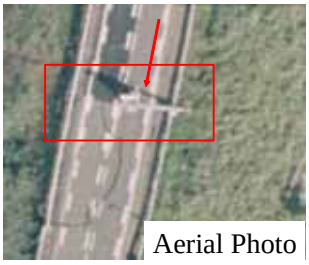

Field Photo

214.9 kp


Aerial Photo


Field Photo

215.2 kp


Aerial Photo

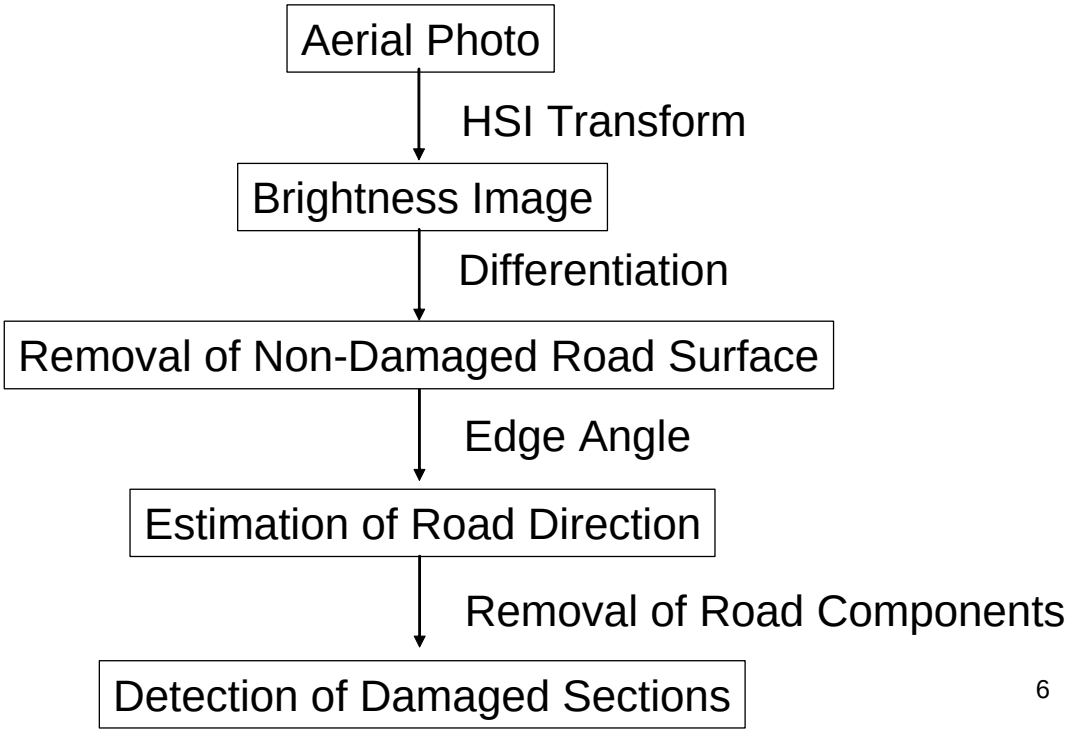

Field Photo

217.3 kp

It takes time to conduct visual damage inspection for the entire area where is subjected to severe ground motion.[5]

Flowchart of Image Processing to Detect the Damaged Sections of Expressways

Automated damage detection based on image processing



HIS Transformation

RGB space

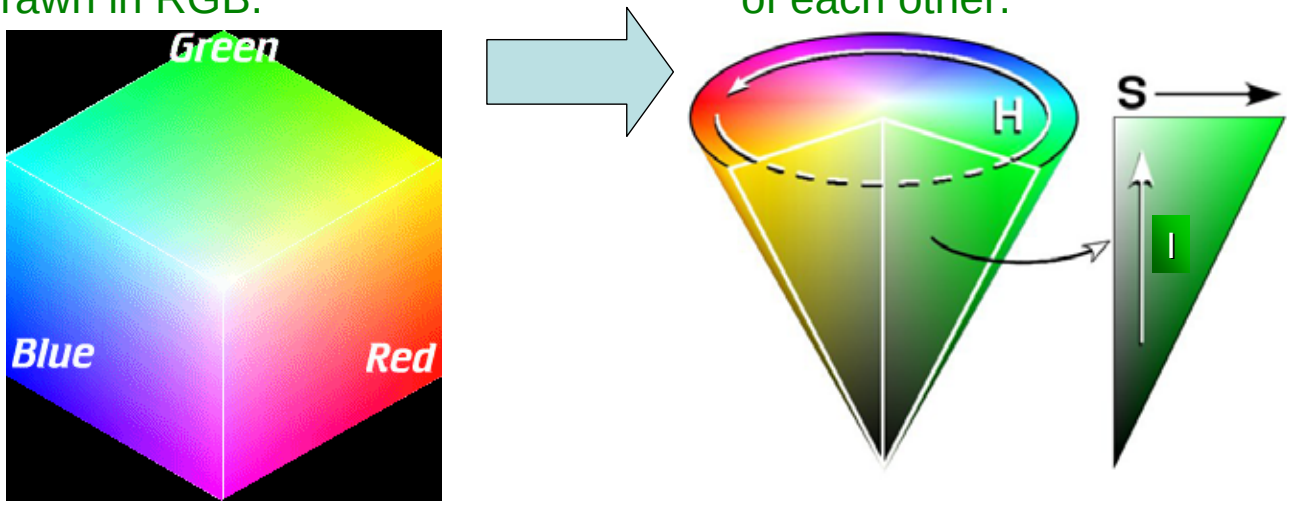
Red
Green
Blue

HIS space

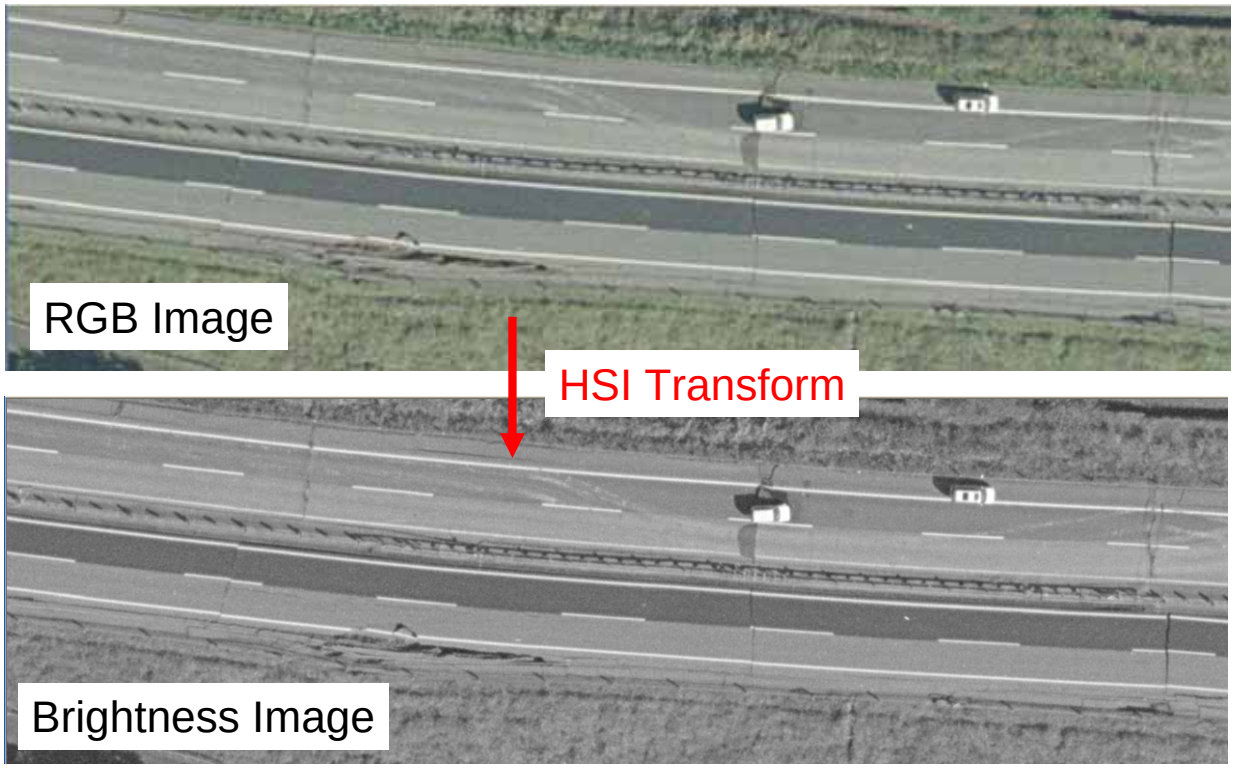
Hue
Saturation
Intensity

Digital color image is drawn in RGB.

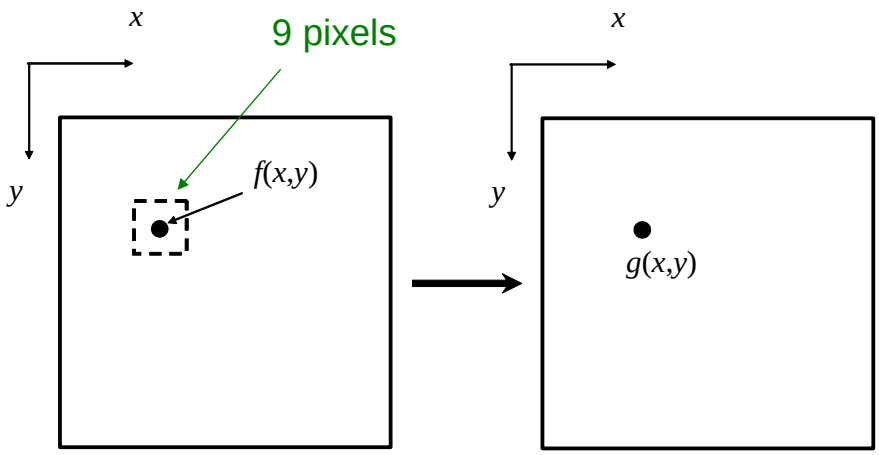
H, S and I are independent of each other.



HIS Transformation



Differential Operation on Images



$$g(x,y) = K\sum_{i=-1}^{1}\sum_{j=-1}^{1} C_{ij}\, f(x+i, y+j)$$

$f(x,y)$: Brightness of the pixel (0～255)
$g(x,y)$: Differential value of the pixel

Sobel Filter

Horizontal Direction

-1	0	1
-2	0	2
-1	0	1

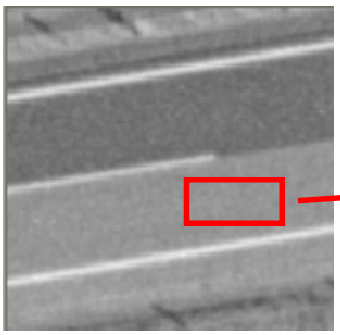
Vertical Direction

-1	-2	-1
0	0	0
1	2	1

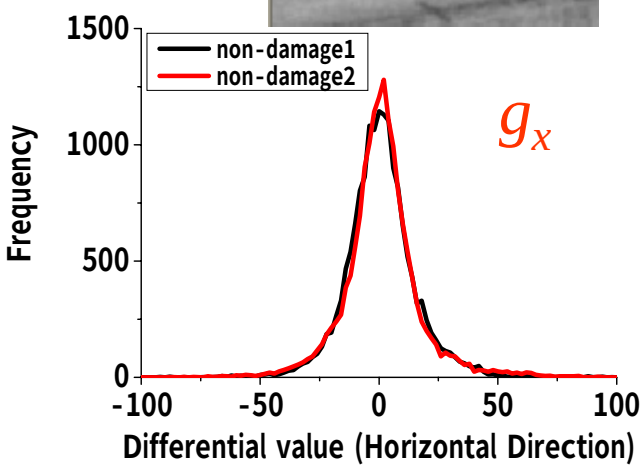
Differential Operation on Images

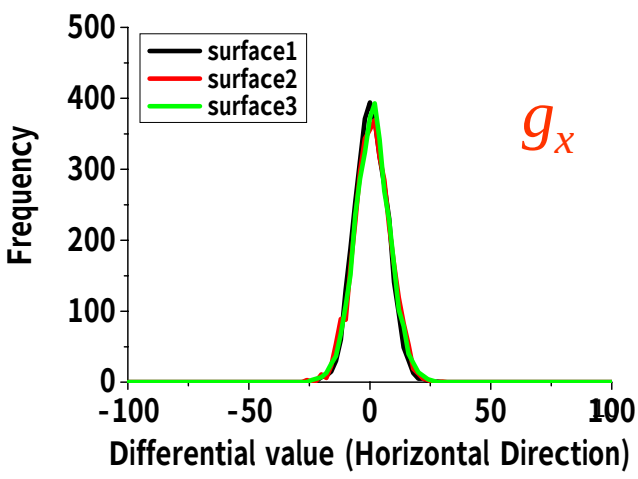
Histogram of differential value

Image with center lines



Road surface image

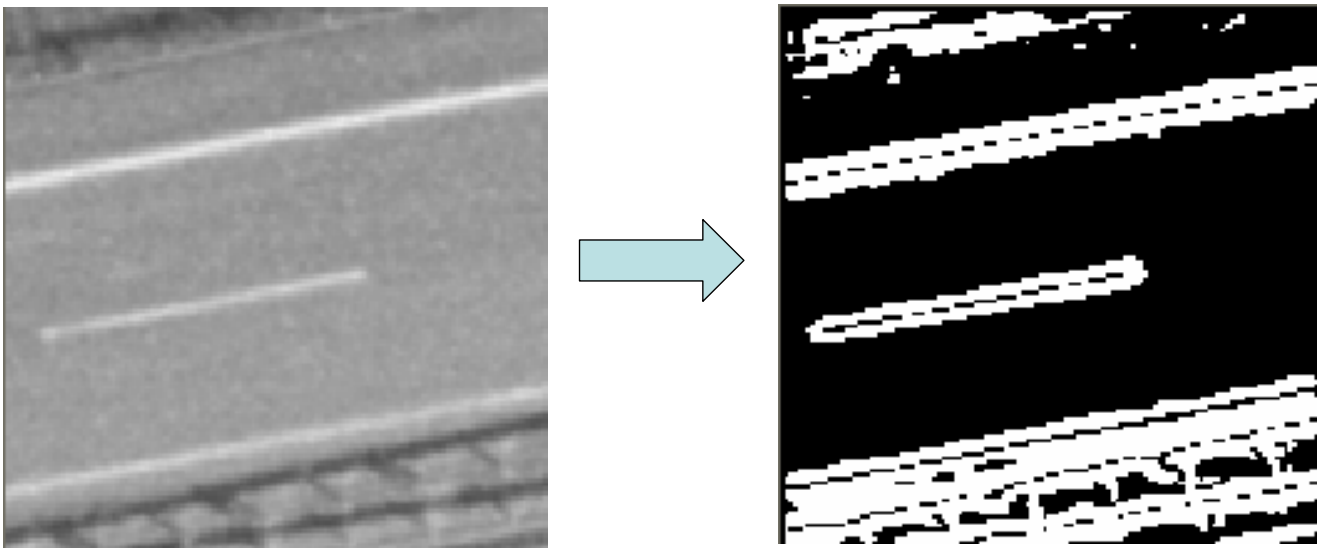




Removal of road surface from the image

$$(|g_x| < c) \cap (|g_y| < c)$$

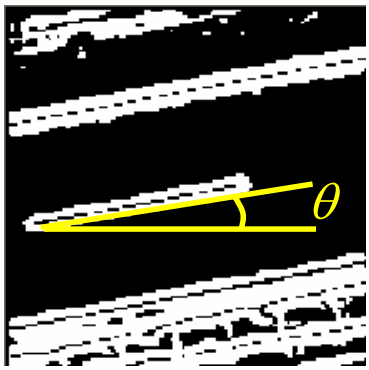
c: threshold value to identify the road surface (= 25)

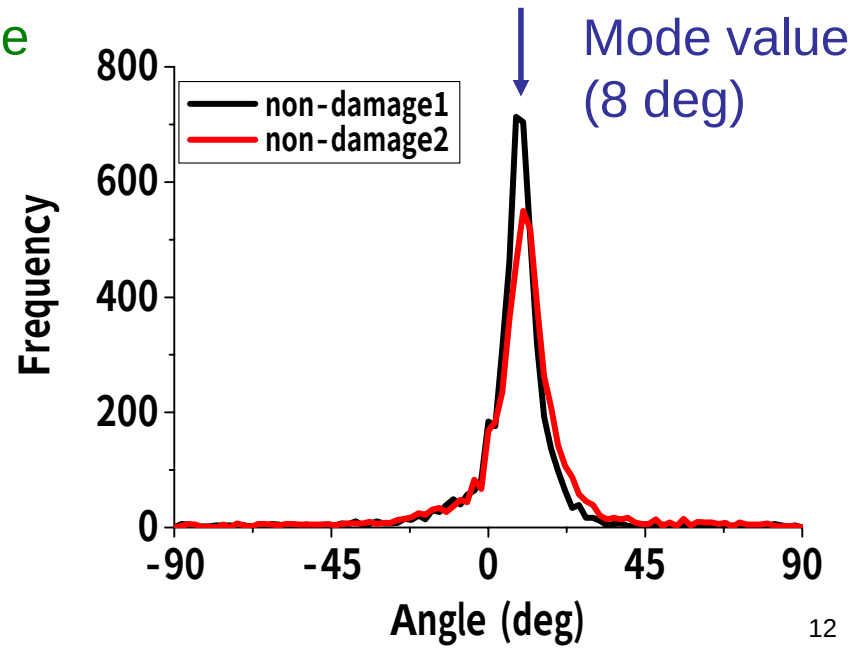


Estimation of Road Direction through Edge Angle

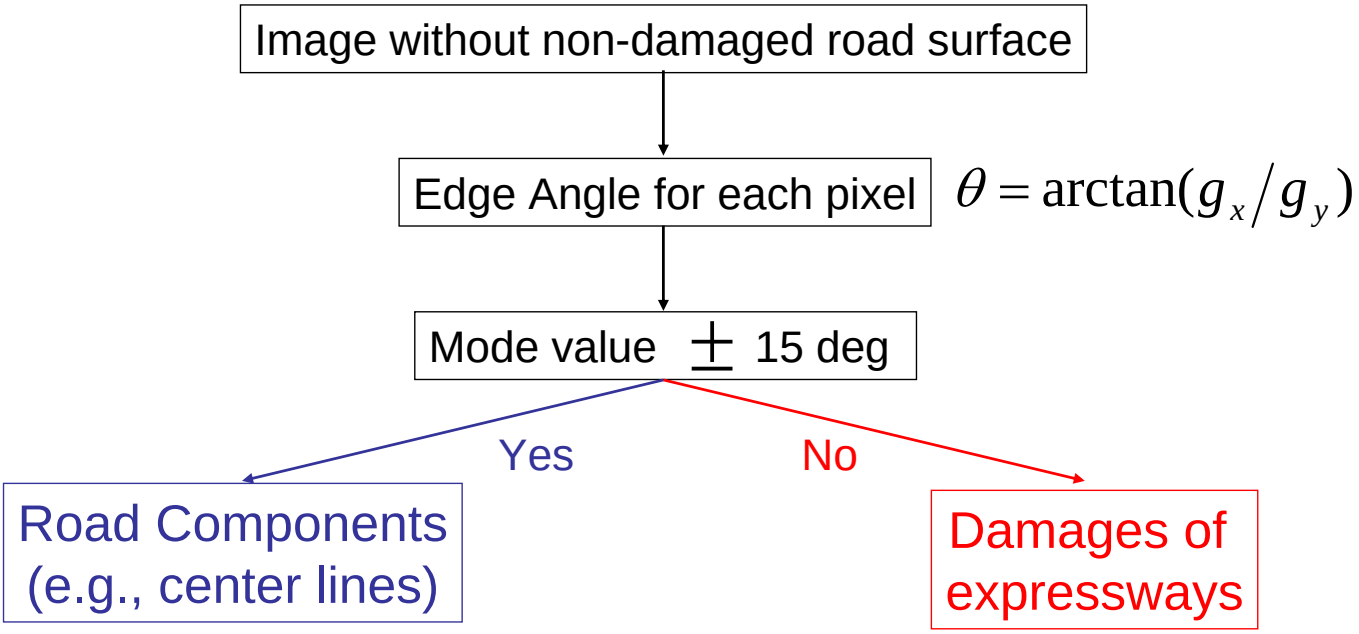
Edge Angle: $\theta = \arctan(g_x / g_y)$

Image without non-damaged road surface

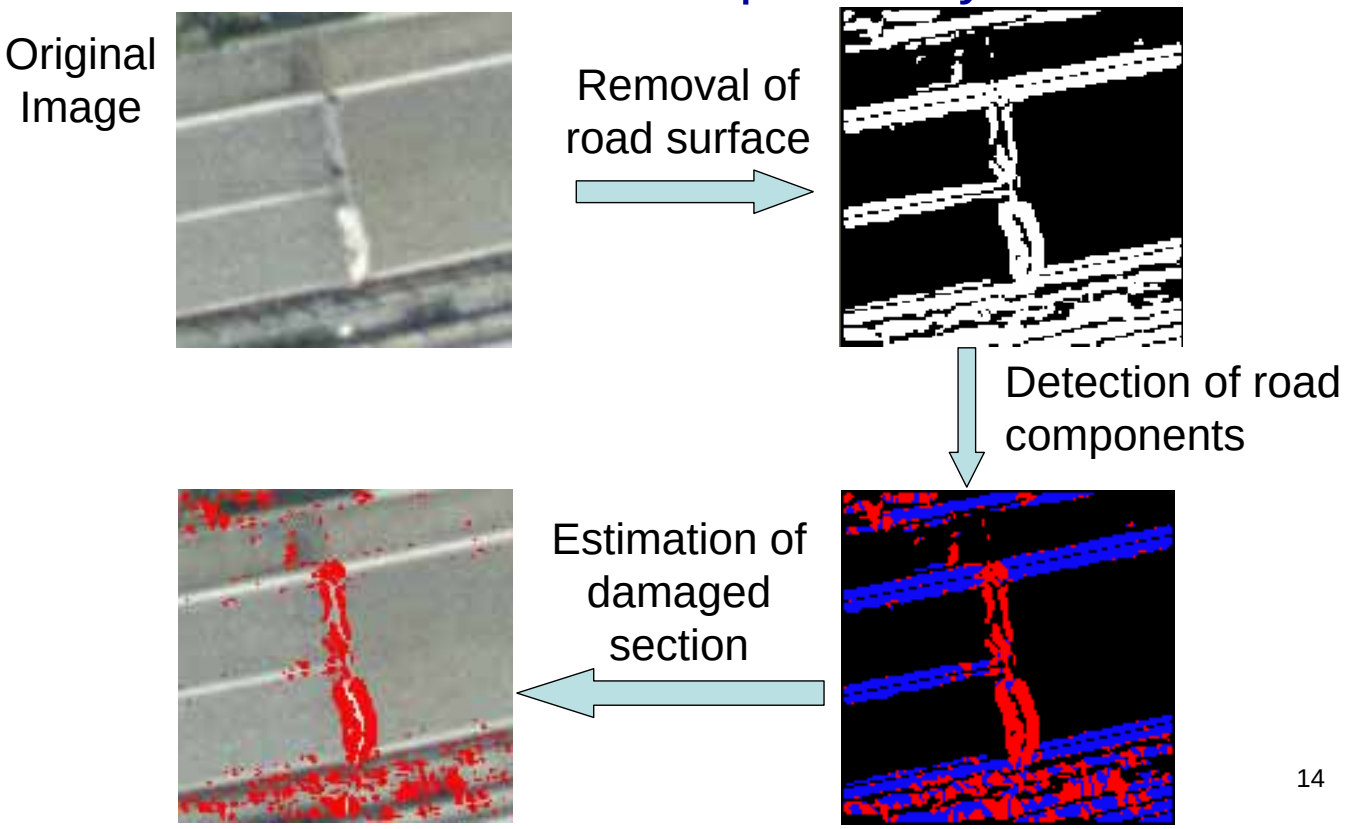




Distinction between Road Components and Damages



Example of Analytical Flow to Detect Damaged Sections of Expressways

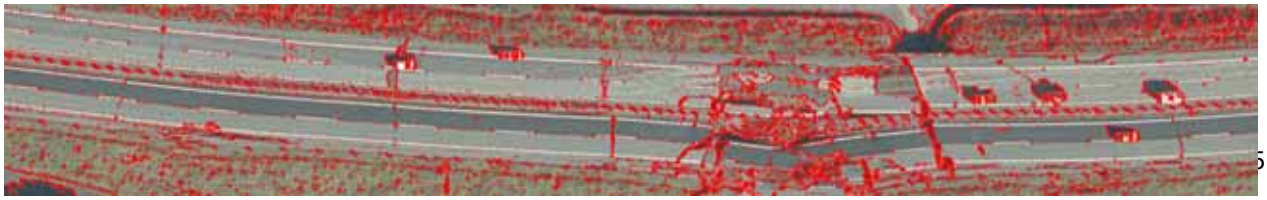


Comparison between the Result of Image Processing and that of Visual Damage Inspection

Aerial Photo

Visual Inspection

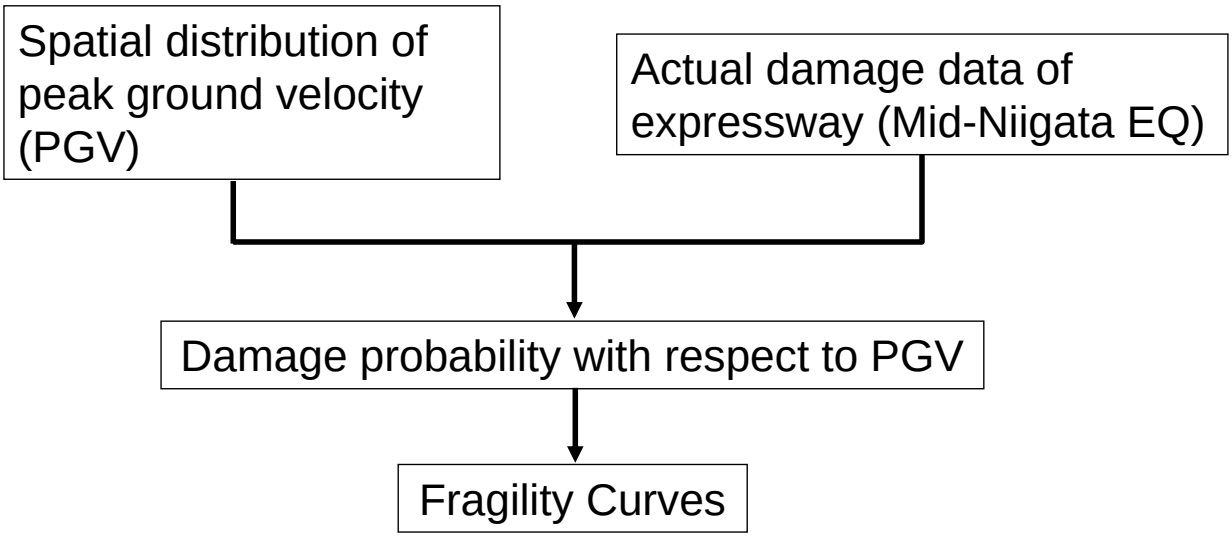
Image Processing



2. Relationship between the damage ratio of expressway embankment and seismic intensity to construct fragility curves

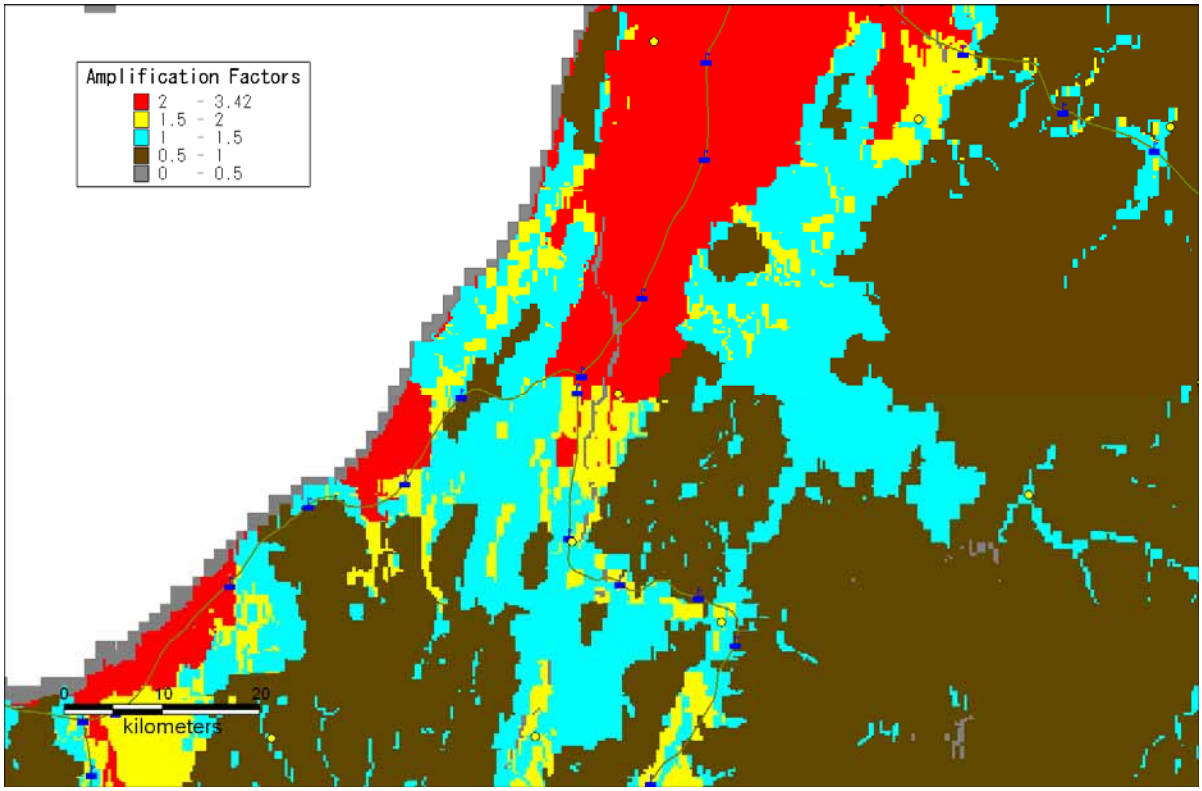
Analytical flow to construct fragility curve of expressway embankment

In order to predict damage probability of expressway embankment just after the earthquake, fragility curves are constructed by statistical analysis.

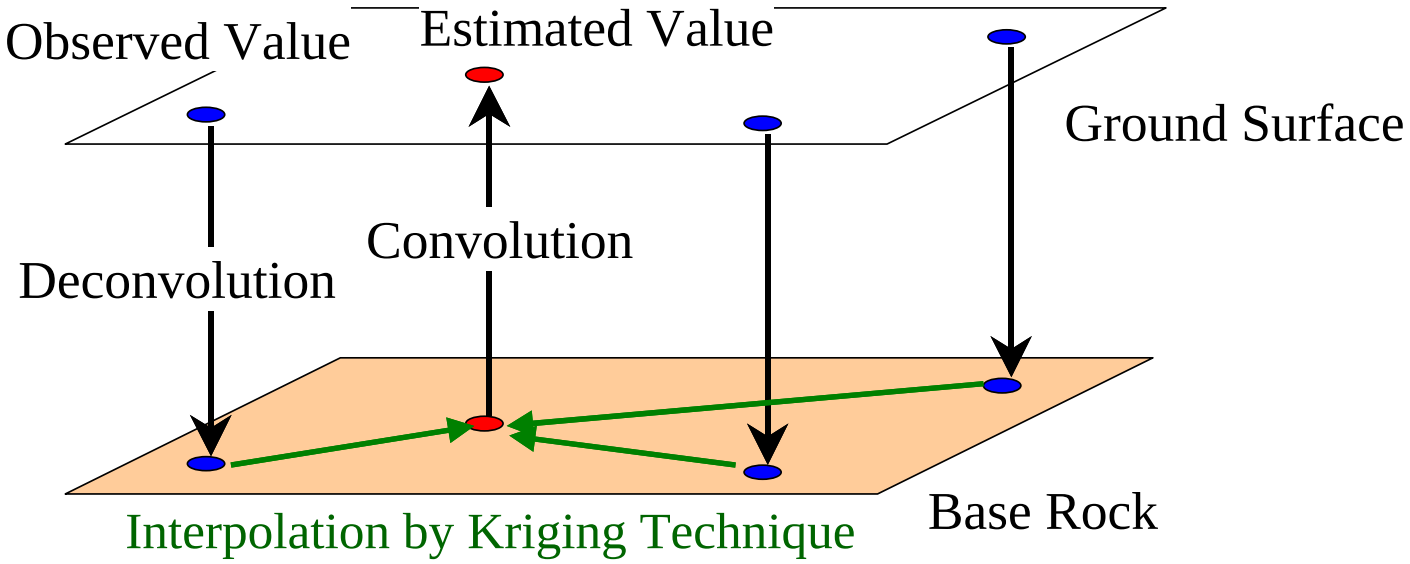


Soil Amplifications with respect to Base Rock (Vs=600m/s)

Matsuoka, et al., 2005

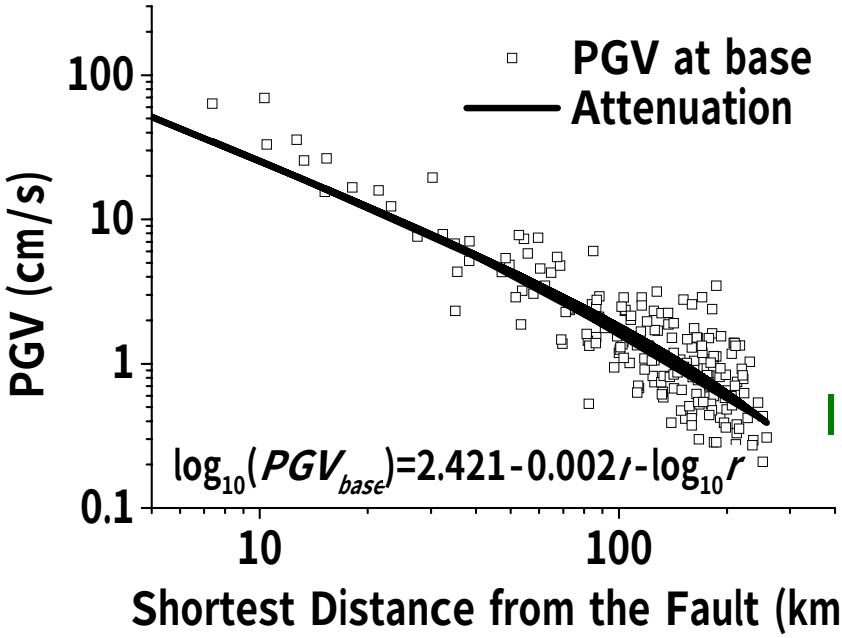


Estimation of Spatial Distribution of PGV based on Kriging Technique



Estimation of Spatial Distribution of PGV based on Kriging Technique

Kriging interpolation at base rock



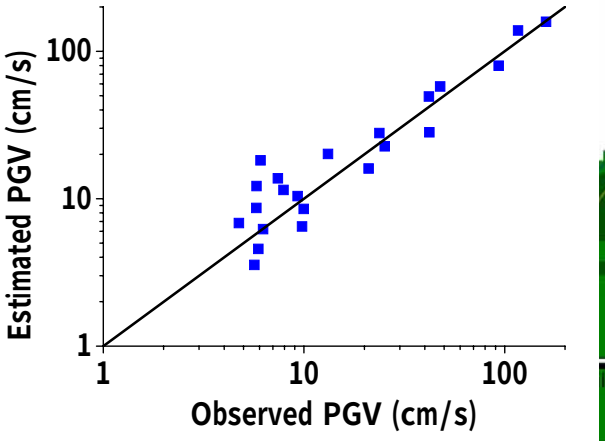
Residual Component

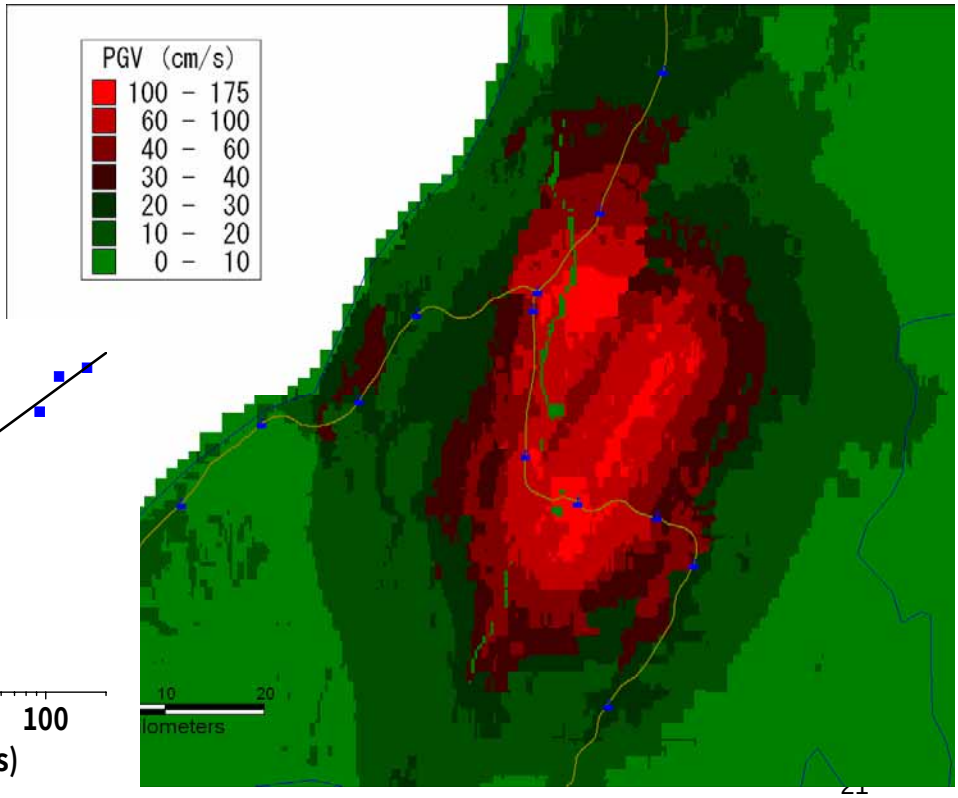
$$X_{PGVi} = PGV_{bi} - PGV_{mi}$$

Interpolated by Kriging Technique

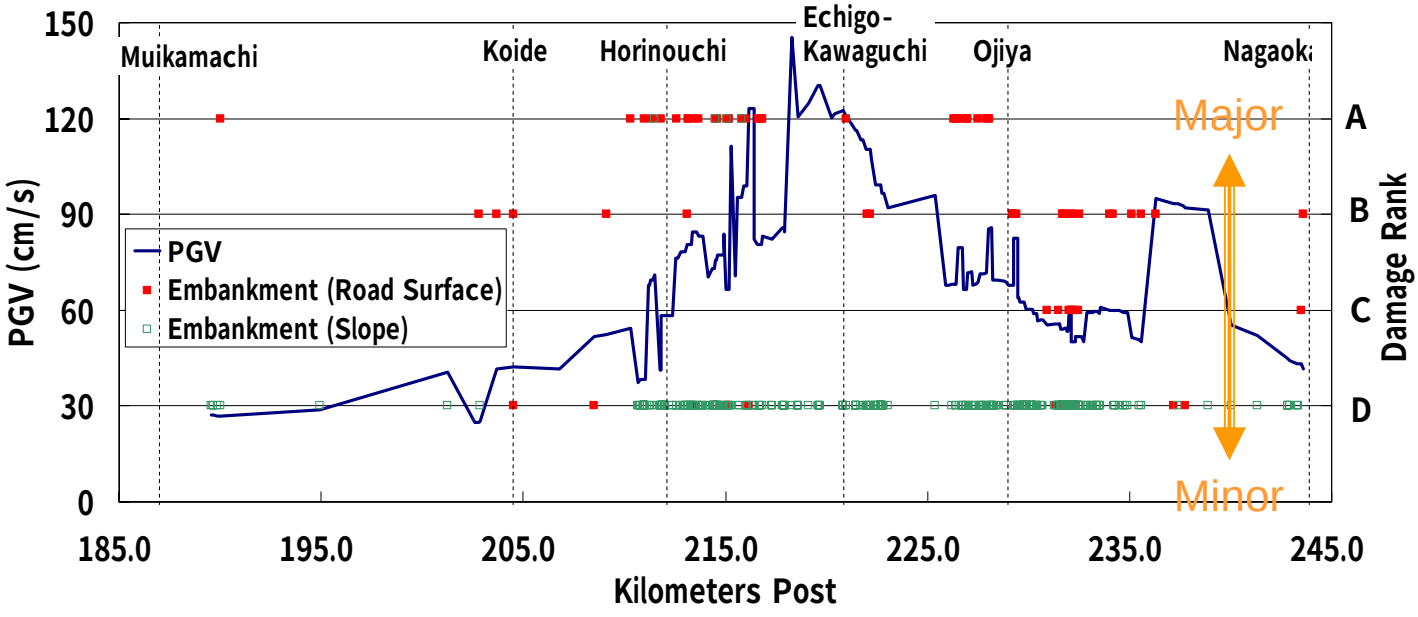
Estimated Distribution of PGV

Accuracy of the estimation





Relationship between Damage Rank and PGV (Kan'etsu Expressway)



Number of Damages of Expressway Embankment (Road Surface)

PGV (cm/s)	Average PGV	A	B	C	D	Length (km)
～30	24.1	3	2	3	4	28.5
30～40	35.3	3	2	0	2	21.8
40～50	44.0	1	3	1	1	10.0
50～60	54.9	1	11	7	17	13.7
60～70	66.0	7	2	0	1	6.0
70～80	74.6	9	1	0	2	6.8
80～100	91.1	11	4	0	3	6.7
100～140	122.1	1	2	0	3	1.9

Damage Probability: $P_R = \dfrac{\text{Number of damages}}{\text{Length (km)}}$

Construction of Fragility Curve

Log-normal distribution

$$P = C\Phi\left(\left(\ln PGV - \lambda\right)/\zeta\right)$$

P: Damage probability
C: Magnification
λ: Mean of variable's logarithm
ζ: Standard deviation of variable's logarithm

Weighted least squares method

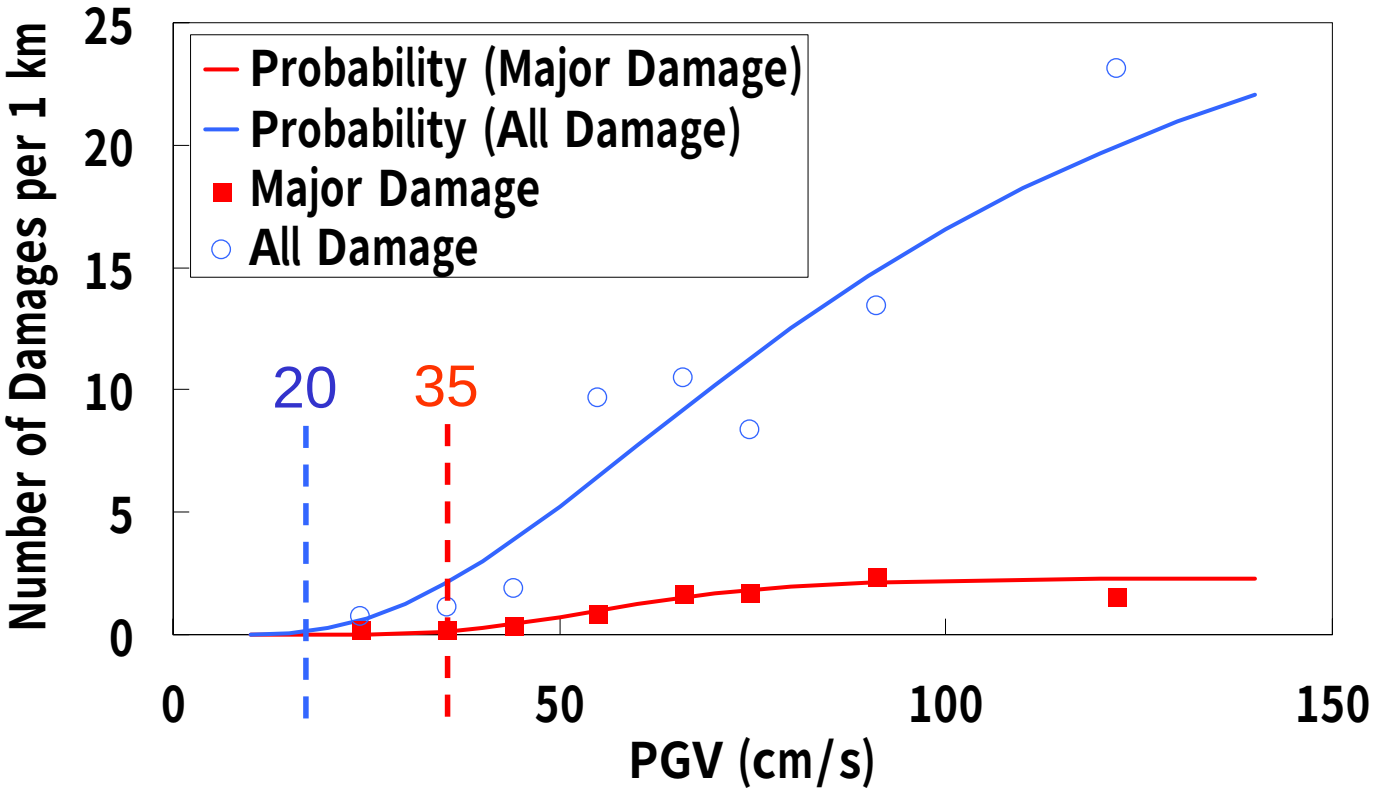
$$\varepsilon = \sum \left(P_R - P\right)^2 w$$

w: Length of the road

C, λ and ζ are determined by non-linear regression analysis

Damage Rank	C	λ	ζ
≥B (Major Damage)	2.29	4.06	0.31
≥D (All Damage)	28.99	4.49	0.64

Fragility Curve of Expressway Embankment



Conclusions

Image Processing of Aerial Photographs

All damaged sections that are recognized visually were classified as damages. However, there remains salt-and-pepper noise in the result of automated damage detection.

Relationship between the damage ratio of expressway embankment and seismic intensity

Fragility curves were constructed based on statistical analysis. Major damages that affect the serviceability for traffic are found in the area where the peak ground velocity (PGV) is larger than about 35.0 cm/s.

These results will be helpful to support a rapid earthquake disaster response in the expressway network.

Thank you very much !