Remote Sensing of Vulnerability: Damage Estimation of Kahramanmaras Earthquake in Turkiye, 2023

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Remote Sensing: principles

Review of past earthquakes studied by remote sensing

Sentinel Asia mission for emergency response

Kahramanmaras earthquake, damage mapping and field displacement
REMOTE SENSING OF VULNERABILITY

• Remote sensing of vulnerability (tectonic movements)

Earthquake vulnerability mapping through optical and synthetic aperture radar (SAR) imageries

• Remote sensing of vulnerability (non-tectonic movements)

Soil consolidation

Land subsidence
REMOTE SENSING FOR MONITORING

- High performance
- Fast actions
- Low labor work
- Cheaper
ELECTROMAGNETIC WAVELENGTH OF OPTICAL AND SAR SENSORS

- Radar wavelengths are considerably longer than visible wavelengths
- SAR sensors can be used in all-weather conditions
- Several different frequencies are used for radar
BEING PASSIVE OR ACTIVE!

Passive (Optical Imagery)

Active (SAR Imagery)

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SAR DAMAGE ASSESSMENT CONCEPT

Intact

Destroyed

As seen by a nadir looking optical sensor

As seen by InSAR (phase difference)

Disaster

1 repeat cycle

1 repeat cycle

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INTERFEROMETRIC SYNTHETIC APERTURE RADAR (INSAR)

- All-weather tool
- Independent of day and night
- Useful tool to study geophysical events
- A practical tool for building damage estimation

Phase correlation

Coherence

©COMET
30 YEARS SAR MISSIONS!
## SAR Remote Sensing of Vulnerability Until 2011

<table>
<thead>
<tr>
<th>Year</th>
<th>Earthquake</th>
<th>Country</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Kocaeli/Gölcük</td>
<td>Turkey</td>
<td>Matsuoka and Yamazaki 2000 [73], Matsuoka and Yamazaki 2002 [102], Ito et al. 2003 [103], Triauni et al. 2010 [104]</td>
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<td>1999</td>
<td>Izmit</td>
<td>Turkey</td>
<td>Bignami et al. 2004 [7], Stramondo et al. 2006 [78], Triauni and Gamba 2009 [105], Triauni et al. 2010 [104]</td>
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<td>1999</td>
<td>Chi-Chi/Great Taiwan</td>
<td>Taiwan</td>
<td>Takenchi et al. 2009 [77], Suga et al. 2001 [92]</td>
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<td>2001</td>
<td>Gujarat</td>
<td>India</td>
<td>Matsuoka and Yamazaki 2002 [102], Yonezawa et al. 2002 [98]</td>
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<td>2003</td>
<td>Boumerdes</td>
<td>Algeria</td>
<td>Triauni and Gamba 2008 [2]</td>
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<td>2003</td>
<td>Bam</td>
<td>Iran</td>
<td>Bignami et al. 2004 [7], Arciniegas 2005 [106], Fielding et al. 2005 [107], Matsuoka and Yamazaki 2005 [100], Stramondo et al. 2006 [78], Arciniegas et al. 2007 [8], Gamba et al. 2007 [94], Hoffmann 2007 [74], Brunner et al. 2010 [108], Triauni et al. 2010 [104]</td>
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<td>2004</td>
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<td>Indonesia</td>
<td>Chini et al. 2008 [9]</td>
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<td>2006</td>
<td>Mid Java</td>
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<td>2007</td>
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<td>Peru</td>
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<td>2007</td>
<td>Chinchca</td>
<td>Peru</td>
<td>Matsuoka and Nojima 2010 [101]</td>
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<td>2009</td>
<td>L’Aquila</td>
<td>Italy</td>
<td>Guida et al. 2010 [114], Dell’Acqua et al. 2011 [115], Cossu et al. 2012 [116], Dell’Acqua and Gamba 2012 [24], Dell’Acqua et al. 2013 [117], Brett and Guida 2013 [118]</td>
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<td>Christophe et al. 2010 [21], Kawamura et al. 2011 [119]</td>
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<td>2010</td>
<td>Haiti</td>
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<td>Uprety and Yamazaki 2012 [10], Brett and Guida 2013 [118]</td>
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<td>2010</td>
<td>Yushu County</td>
<td>China</td>
<td>Jin et al. 2011 [120]</td>
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<td>2011</td>
<td>Tohoku</td>
<td>Japan</td>
<td>Chini et al. 2013 [121]</td>
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</table>
## SAR REMOTE SENSING FOR VULNERABILITY (2011-2021)

- My personal research activity

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<th>Year</th>
<th>Earthquake</th>
<th>Country</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Ahar-Varzaghan</td>
<td>Iran</td>
<td>Karimzadeh et al., 2017</td>
</tr>
<tr>
<td>2016</td>
<td>Amatrice</td>
<td>Italy</td>
<td>Karimzadeh and Matsuoka 2017; Karimzadeh and Matsuoka 2018</td>
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<td>2016</td>
<td>Kumamoto</td>
<td>Japan</td>
<td>Hajeb et al., 2019</td>
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<td>2017</td>
<td>Kermanshah</td>
<td>Iran</td>
<td>Karimzadeh et al., 2018; Hajeb et al., 2020; Omarzadeh et al., 2021;</td>
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<td>2018</td>
<td>Eastern Iburi</td>
<td>Japan</td>
<td>Karimzadeh and Matsuoka 2018</td>
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<td>2020</td>
<td>Petrinja</td>
<td>Croatia</td>
<td>Karimzadeh and Matsuoka 2021</td>
</tr>
</tbody>
</table>
DAMAGE MAPPING IN COLLABORATION WITH SENTINEL ASIA

2023-02-06

Earthquake in Turkey on 06 February, 2023

Emergency Obs. Request Information

Disaster Type: Earthquake
Country: Turkey
Occurrence Date (UTC): 06 February, 2023
SA activation Date(UTC): 06 February, 2023

Requester: Disaster & Emergency Management Presidency of Turkey (AFAD)
Escalation to the International Charter: No
GLIDE Number: EQ-2023-000015-TUR
SENTINEL ASIA FRAMEWORK

Technological Progress

New Satellites
New Technology

Step 1
2006-2007
Pilot project

Lessons
Learned
from Step 1

Step 2
2008-2012

Lessons
Learned
from Step 2

Step 3
2013 onwards

User Requirements

Users: JPT Members, Disaster Management Organizations

© Sentinel Asia
Concept of Sentinel Asia Step 3

- **Pre-disaster Mitigation**: Community education
- **Preparedness**: Hazard map, Early warning system
- **Just after disaster Response**: Emergency observation
- **Post-disaster Recovery**: Monitoring

Information sharing (Web-GIS)

Human network
Capacity Building, Outreach
BACKGROUND AND OBJECTIVE-1

- The earthquakes that struck southeastern Turkey on February 6, 2023, caused extensive damage in Turkey and Syria. Because of the large extent of the damage, the damage information reported from the affected areas after the earthquake did not provide a complete picture of the damage situation, and observation images from satellites equipped with high-resolution optical sensors only cover a limited number of cities. The images are affected by weather conditions, and therefore, the damage situation could not be grasped uniformly.
- One of the observation modes of the weather-independent synthetic aperture radar (SAR)-equipped satellites is the wide-area observation function (ScanSAR). Since the affected areas were observed on February 17 and 20 after the earthquake, we examine here whether the damage to buildings could be estimated from PALSAR-2 ScanSAR imagery whose spatial resolution is rather coarse (approx. 30 m).
- Although these images were taken more than 10 days after the earthquake and include not only the immediate post-earthquake situation but also disaster relief activities, we believe that the results provide basic data to demonstrate the effectiveness of the wide-area observation mode in understanding huge disasters such as this event.
BASIC APPROACH FOR DAMAGE ESTIMATION FROM SAR INTENSITY

✓ Image matching
✓ Speckle noise filtering
✓ Calculating following indices,
  ✓ Difference of backscattering coefficient (after – before)
    \[
    \text{damage} < \text{no damage}
    \]
✓ Correlation coefficient
  \[
  \text{damage} < \text{no damage}
  \]
BACKGROUND AND OBJECTIVE-2

• We already developed C- and L-bands SAR-based damage estimation models with integration of seismic intensity information based on satellite images observed the 1995 Kobe earthquake and its detailed ground truth data (Nojima et al., 2006; Matsuoka and Nojima, 2010).

• We also developed a discriminant equation for damage estimation with integration of phase and intensity information and its detailed ground truth data for Amatrice (2016) and Kermanshah (2017) earthquakes (Karimzadeh and Matsuoka 2016; Karimzadeh et al., 2018).

• Since these studies have included models (Likelihood Functions) that estimate severe building damage rates from SAR images only, we applied the L-band SAR model to the in Turkey-Syria earthquakes.
METHODOLOGY

• Variable: SAR intensity difference and correlation

• Procedure: pixel selection for seven damage classes (severe damage ratio) to examine the relationship between indices and damage classes, and proposing following two functions:

  – Combined index, $ZR$, (discriminant score) from Regression discriminant function

  – Likelihood function (fragility function) to estimate severe damage ratio from $ZR$
DISCRIMINANT SCORE AND LIKELIHOOD FUNCTIONS

ERS-1 (C-band)

\[ Z_R = -1.210 \, d - 4.360 \, r \]

\( Z_R, Z_{Rj} \): discriminant score
\( d \): intensity difference
\( r \): correlation

JERS-1 (L-band)

\[ Z_{Rj} = -1.277 \, d - 2.729 \, r \]
RELATIONSHIP BETWEEN Z_R AND DAMAGE RATIO

This curve is equivalent to the fragility function for damage without seismic intensity information, the severe damage ratio increases with increasing Z_R.
FLOWCHART OF DAMAGE ESTIMATION

Equation:
\[ d = 10 \cdot \log_{10} \frac{\hat{I}_d}{\hat{I}_p} - 10 \cdot \log_{10} \frac{\hat{I}_b}{\hat{I}_p} \]  
(1)

\[ r = \frac{N \sum_{i=1}^{N} I_a I_b - \left( \sum_{i=1}^{N} I_a \right) \left( \sum_{i=1}^{N} I_b \right)}{\sqrt{N \sum_{i=1}^{N} I_a^2 - \left( \sum_{i=1}^{N} I_a \right)^2} \sqrt{N \sum_{i=1}^{N} I_b^2 - \left( \sum_{i=1}^{N} I_b \right)^2}} \]  
(2)

where \( i \) is the sample number, and \( I_a \) and \( I_b \) are the digital numbers of the post- and pre-images, respectively. \( I_a \) and \( I_b \) are the corresponding averaged digital numbers over the surroundings of pixel \( i \) within a 13 x 13 pixel window; the total number of pixels \( N \) within this window is 169.

Note:
*1 Pixel size: Equal to the size of spatial resolution of satellite’s sensor
*2 Pixel value: Power
*3 Tie point selection: Correlation method
*4 Registration: Affine transformation
*5 Pre-processing: Loo filter
*6 Window size: 13 x 13 pixel
*7 Difference (post - pre): Average value within a window
*8 Threshold: approx. <-5dB of pre-earthquake SAR image
*9 Model: Likelihood functions for building damage estimation based on the dataset from the 1995 Kobe earthquake

Urban Footprint Data (DLR)
PALSAR-2 SCANSAR IMAGERY

Acquisition date and specifications

<table>
<thead>
<tr>
<th>Date</th>
<th>Path</th>
<th>Beam</th>
<th>Look</th>
<th>Orbit</th>
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<td>2022/9/5</td>
<td>184</td>
<td>W2</td>
<td>R</td>
<td>Asc.</td>
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<td>R</td>
<td>Des.</td>
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<td>2023/2/17</td>
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<td>R</td>
<td>Des.</td>
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<tr>
<td>2023/2/20</td>
<td>184</td>
<td>W2</td>
<td>R</td>
<td>Asc.</td>
</tr>
</tbody>
</table>

Spatial resolution: approx. 30 m
Polarization: HH

Building damage estimation for each pre- and post-earthquake pair of ascending and descending orbits, respectively.
DISCRIMINANT SCORE Z_{RJ} MAP

Ascending pair

Descending pair
DAMAGE PROXY MAP (DAMAGE RATIO)
DAMAGE PROXY MAP (DAMAGE RATIO)
DAMAGE PROXY MAP (DAMAGE RATIO)
DAMAGE PROXY MAP (DAMAGE RATIO)
WIDE-AREA DAMAGE PROXY MAPPING BY ALOS-2 SCANSAR IMAGERY ACQUIRED AFTER THE 2023 TURKEY EARTHQUAKES

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³ Gifu University, Gifu, Japan
⁴ University of Tabriz, Tabriz, Iran
KAHRAMANMARAS SENTINEL-1 INTERFEROGRAM

Initial deformation map of Kahrmanmaras earthquakes. Two Sentinel-1 single look complex (SLC) images are used for interferogram generation. The pre-event image is acquired in 2023.01.28 and the post-event image is acquired in 2023.02.09. The results show that each fringe is 2.8 cm displacement in the line of sight of satellite (red arrow).
DAMAGE PROXY MAP FROM SENTINEL-1

InSAR coherence damage map after Kahramanmaras earthquake, Turkey (2023.02.06).

Remote sensing laboratory in University of Talca, Iran, in collaboration with Osaka Technical University, Japan, and Tokyo Institute of Technology, Japan, produced the initial damage map of the settlements in Turkey and Syria after M 7.8 and M 7.5 earthquakes. Sentinel-1 satellite images collected by European Space Agency (ESA) were used for coherence generation. The results are generated from orbit 14 between 10 Jan. 2023 and 9 Feb. 2023. Red pixels indicate high damage change probability, while yellow and blue indicate medium and negligible change, respectively. Green circles indicate medium damage possibility and white pixels represent negligible change. All damage maps are available at www.irst.x (remote sensing laboratory, University of Talca, Iran).


Disclaimer: the results are initial and all the red pixels are not representative of damaged buildings.
DAMAGE PROXY MAP OVER HATAY
RGB MAP OF KAHRAMANMARAS (PALSAR-2)

2023.02.06
Kahrmanmaras Earthquakes

ALOS-PALSAR-2 RGB building orientation map in Kahramanmaras, Turkey

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R = HH 2022.04.06
G = HV 2023.02.08
B = HV 2023.02.08
RGB MOOD MAP OF ANTAKYA AND GAZIANTEP
THANK YOU!

Any question?!