AN URBAN DAMAGE SCALE BASED ON SATELLITE AND AIRBORNE IMAGERY

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SUMMARY

In the last decade, remote sensing technologies have played increasing roles in quantifying the extent of damage during large earthquakes. This has been especially true for several recent foreign events, i.e., the 1999 Marmara, Turkey, the 2001 Bhuj, India, the 2003 Boumerdes, Algeria, the 2003 Bam, Iran and the 2004 Morocco earthquakes. Furthermore, remote sensing technologies played an important role in identifying hard hit areas – both water and windborne damage - after Hurricane Katrina in the U.S. Because of advances and improvements in deployment and resolution, commercial satellite data providers are now able to provide near real-time, high-resolution imagery following major catastrophes.

Despite the fact that numerous methodologies have been proposed for measuring the effects of disasters using remotely sensed data, there is yet to be developed a standard scale for quantifying damage and impacts using these data. Part of the reason for this is that the quality (resolution, timeliness and spectral properties) of remotely sensed data has improved only in the last several years and researchers have not had enough time to test and validate their damage detection approaches.

This paper proposes the requirements of a regional damage scale for measuring the effects of earthquakes, floods and windstorms using high-resolution optical and synthetic aperture radar (SAR) data. The basis for this scale comes from recommendations made at two EERI-MCEER-UCI sponsored workshops (2003, 2004) where the focus was on the application of remote sensing technologies for disaster response and recovery. Many of the participants in these two workshops are current members of EERI's Subcommittee on Remote Sensing.

INTRODUCTION

The benefits of a standard scale for damage assessment are significant. By establishing common damage states (e.g., collapse, partial collapse, etc.) and identifying key indices that accurately quantify these states, rapid assessments of damage for large regions can be conducted within a matter of days. Research has shown that rapid and accurate damage assessments can reduce the overall impacts of a large disaster by helping to prioritize important response activities and preventing cascading events (e.g., release of hazardous materials). A standard scale will also provide a basis for collecting and archiving important satellite imagery for future research.

Figure 1 shows a comparison of before and after event imagery for the Boumerdes, Algeria earthquake in 2003. The availability of high-resolution imagery has significantly changed our expectations with regard to regional damage assessment using remotely sensed data. The next section discusses a few studies that have use this high-resolution data to determine the damage levels of areas impacted most by large earthquakes.

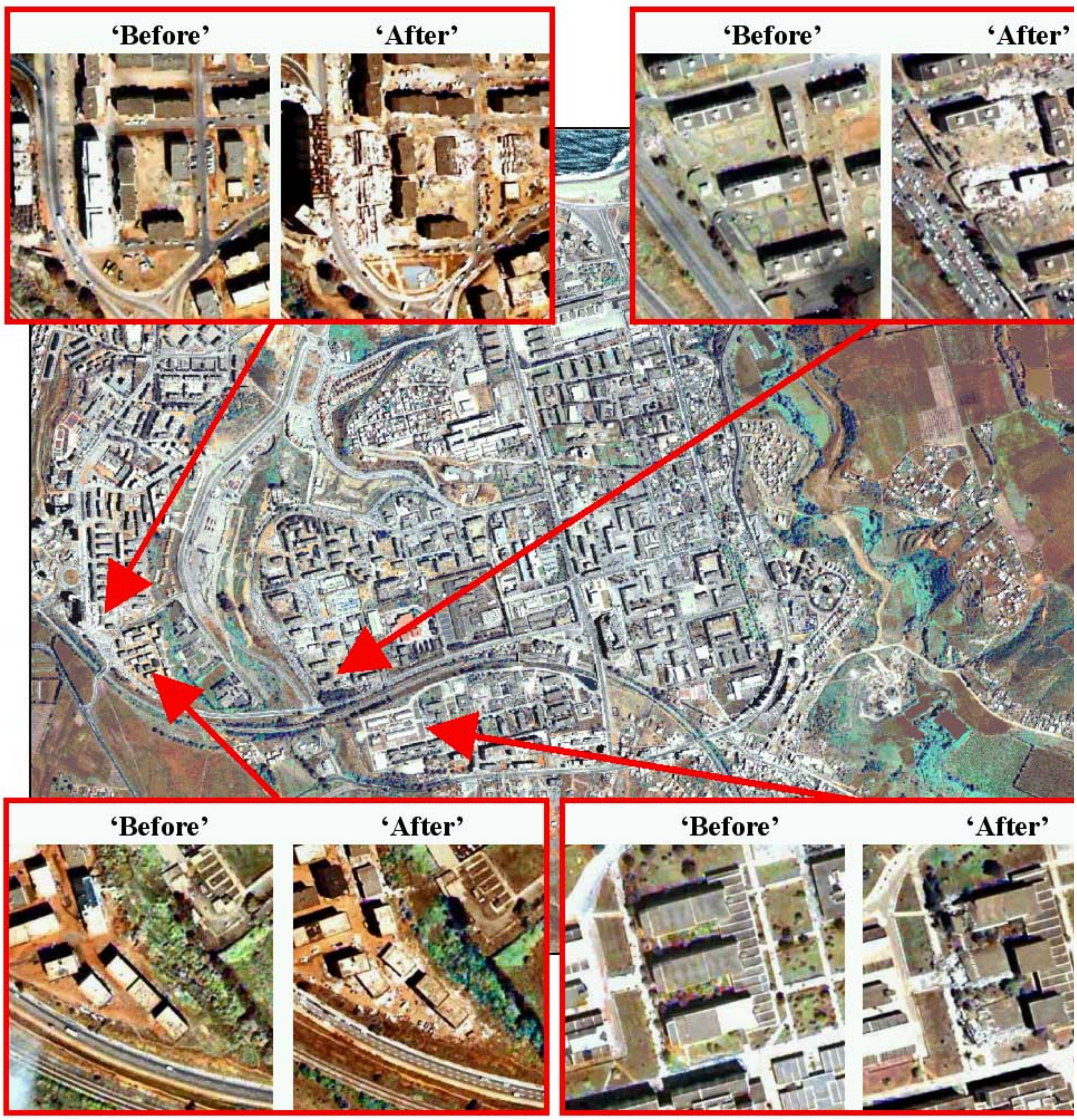

FIGURE 1 Selected examples of building damage in the city of Boumerdes, identified by visual inspection of pan-sharpened Quickbird imagery, acquired before and after the 5/21/03 earthquake. Images courtesy of DigitalGlobe, www.digitalglobe.com

DAMAGE STUDIES

To date, there have been ten major earthquakes where damage has been measured using remotely sensed data: 1993 Hokkaido, Japan; 1995 Kobe, Japan; 1999 Marmara, Turkey; 2001 Bhuj, India; 2001 San Salvador, El Salvador; 2001 Atico, Peru; 2003 Boumerdes, Algeria; 2003 Bam, Iran; 2004 Niigata, Japan; and 2004 South Asia earthquake and tsunami. In each of these events, different sensors were used, as were different methodologies for quantifying damage. The ability to more accurately identify severely damaged areas with remotely sensed data has improved considerably in the last several years, largely as a result of commercially-available high-resolution satellite imagery.

Figure 2 summarizes research on some of the events above. In theoretical terms, a basic distinction can be drawn between *direct* approaches, where damage is recorded through its signature within the imagery versus *indirect* indicators, using a surrogate measure such as nighttime lighting levels (Hashitera *et al*., 1999). Within the realm of direct damage detection, studies are based on either *mono-* or *multi-temporal* analysis. While the former distinguishes between the appearance of damaged and non-damaged structures within a given scene (see, for example, Mitomi *et al*., 2000, 2001, 2002), the latter infers damage in terms of change between a temporal sequence of images. Multi-temporal damage detection is an extremely active research area, where considerable progress is attributable to collaborative efforts between U.S. and Japanese investigators.

A number of intermediary reports document progress made with the development of qualitative and quantitative approaches to damage detection based on satellite imagery (see Eguchi *et al*., 2000a, 2000b, 2003a, 2003b; also Matsuoka and Yamazaki, 2000a, 2000b, 2002, 2003). These studies employ optical and radar coverage. Optical sensors such as SPOT and Landsat are widely used in earth observation. Images are easy to interpret as they depict the ground surface as it appears to the human eye. Although more difficult to interpret as it records surface geometry, radar imagery has the advantage of 24/7, all weather viewing capability. As shown in Figure 2, both types of imagery have been implemented for a range of earthquakes including the 1995 Kobe, 1999 Marmara and 2001 Bhuj events.

DAMAGE SCALES

Various damage scales have been used to measure the effects of earthquakes. One of the more popular scales is the European Macro-seismic Scale (EMS98). This scale provides visual and descriptive information on damage to masonry and reinforced-concrete buildings, as measured in five categories: Grade 1: negligible to slight damage; Grade 2: moderate damage; Grade 3: substantial to heavy damage; Grade 4: very heavy damage; and Grade 5: destruction or collapse. Yamazaki et al. (2004) and Matsuoka and Yamazaki (2004) utilized this scale in quantifying damage in a number of earthquakes including the Bam, Iran earthquake. In general, only damage states 1, and 4 and 5 are easily detectable using remotely sensed data (Huyck et al., 2004).

Huyck et al.(2004), developed a regional scale which quantified the percentage of collapsed or severely damage structures in moderate-sized zones. They used the following ranges of observed collapsed buildings to measure the severity of damage in two regions affected by the 1999 Marmara, Turkey earthquake: 0-6.25%; 6.25-12.5%; 12.5-25%; 25-50%; and greater than 50% collapsed structures. The results generally show that an increase in these values/ranges correlates well with an increase in change between before and after satellite imagery. This relationship holds true for different sensors (SPOT, and ERS) and using different change detection indices (correlation, coherence, and intensity difference).

Simpler measures have been successfully employed in some recent events using high-resolution imagery. As opposed to measuring large areas of significant damage, some investigators have attempted to identify damage to specific buildings. Using Quickbird satellite images of the Boumerdes, Algeria earthquake, Rathje and Crawford (2003) applied semi-automated thematic classification algorithms to identify collapsed and pancaked buildings using only post-earthquake, pan-sharpened images. In addition, Saito and Spence (2004) used a texture-based analysis, namely semivariograms (in conjunction with spectral information), to classify four levels of debris in the Bam, Iran earthquake: debris with very rough texture; debris of a heavily damage or partially collapsed building; debris with high reflectance, and debris with comparatively lower reflectance.

STANDARDIZED SCALE – REQUIREMENTS

A standardized scale is needed in order to ensure consistent interpretation of remotely sensed images and data. Assessments that could potentially be based on these data and their use in damage detection algorithms include:

- Identification of areas of significant damage and disruption,
- Number of collapsed buildings or structures,
- Number of people killed or injured (based on the building damage assessments),
- Areas of inundation (caused by dam failure or tsunami), and
- Areas of utility outage (as measured by lack of power or nighttime lights).

Some of the requirements that should be addressed in establishing this scale include:

1. At a minimum, the damage scale must distinguish between collapsed and non-collapsed structures.
2. The scale must distinguish between image changes caused by building damage and those that reflect normal ambient effects, e.g., seasonal changes.
3. Ideally, the scale will identify the following structural damage states: tilting of buildings, and soft-story collapses or failures.

4. The scale should be employed using a variety of sensors, including optical (high-resolution), radar, and LIDAR.
5. The scale should distinguish damage to buildings and other infrastructure, such as roadways, bridges, utility equipment.
6. The scale should distinguish damage to residential, commercial and industrial facilities.
7. The scale should be updatable as new and better sensors emerge.

In the last meeting of EERI subcommittee (in 2004), the following challenges were identified in creating a standardized scale:

- Being able to agree on meaningful damage states,
- Fusing data from different sensors with different scales, spectral properties, temporal frequencies,
- Lack of ground truth data to corroborate damage assignments made from remotely-sensed data,
- Gap in understanding between users and technology developers,
- Overcoming barriers to acceptance. We have the technology, but potential users have yet to implement it. Why?

The discussion above is just the beginning of a more extended set of discussions that must occur among experts who are doing work on damage assessment using remote sensing technologies. So far, there have been two meetings in the last two years of the EERI Subcommittee on Remote Sensing. This particular meeting (Chiba, September 12-13, 2005) will represent the third meeting of this group. A major agenda item of the Chiba meeting will be the development of a standardized damage scale using remotely sensed data.

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REFERENCES

1. Adams, B.J., Huyck, C.K. and Eguchi, R.T. (2003) *The Boumerdes (Algeria) Earthquake of May 21, 2003: Preliminary Reconnaissance Using Remotely Sensed Data*, http://mceer.buffalo.edu/research/boumerdes/default.asp.

2. Andre, G., Chiroiu, L., Mering, C. and Chopin, F. (2003) Building destruction and damage assessment after earthquake using high resolution optical sensors. The case of the Gujurat earthquake of January 26, 2001, *Proceedings of the IGARSS 03*, Toulouse.
3. Chiroiu, L. and Andre, G. (2001) *Damage assessment using high resolution satellite imagery: application to 2001 Bhuj, India earthquake*, www.riskworld.com.
4. Chiroiu, L., Andre, G., Guillande, R., and Bahoken, F. (2002) Earthquake damage assessment using high resolution satellite imagery, *Proceedings of the 7th U.S. National Conference on Earthquake Engineering*, Boston.
5. Chiroiu, L., Andre, G. and Bahoken, F. (2003) *Earthquake loss estimation using high resolution satellite imagery*, www.gisdevelopment.net/application/natural_hazards/earthquakes/nheq0005.htm.
6. EDM, 2000, *Report on the Kocaeli, Turkey Earthquake of August 17, 1999*, Technical Report Series No. 6, EDM (Riken): Miki.
7. Eguchi, R.T., Huyck, C.K., Houshmand, B., Mansouri, B., Shinozuka, M., Yamazaki, F. and Matsuoka, M. (2000a) The Marmara Earthquake: A View from Space, In Scawthorn, C. (ed.) *The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report, Section 10, Technical Report MCEER-00-0001,* MCEER: Buffalo.
8. Eguchi, R.T., Huyck, C.K, Houshmand, B., Mansouri, B., Shinozuka, M., Yamazaki, F. and Matsuoka, M. and Ulgen, S. (2000b) The Marmara, Turkey earthquake: Using advanced technology to conduct earthquake reconnaissance, *MCEER research and Accomplishments1999-2000,* MCEER: Buffalo.
9. Eguchi, R.T., Huyck, C.K., Adams, B.J., Mansouri, B., Houshmand, B. and Shinozuka, M. (2003a) Earthquake damage detection algorithms using remotely sensed data – Application to the August 17, 1999 Marmara, Turkey earthquake, *Proceedings of the 7th EERI US/Japan Workshop on Urban Earthquake Hazard Reduction*, Maui.
10. Eguchi, R.T., Huyck, C.K., Adams, B.J., Mansouri, B., Houshmand, B., and Shinozuka, M (2003b) Resilient disaster response: Using remote Sensing technologies for post-earthquake damage detection, *MCEER research and Accomplishments 2001-2003*, MCEER: Buffalo.
11. Estrada, M., Kohiyama, M., Matsuoka, M. and Yamazaki, F. (2001a) Detection of damage due to the 2001 El Salvadore earthquake using Landsat images, *Proceedings of the 22nd Asian Conference on Remote Sensing*, Singapore.
12. Estrada, M., Matsuoka, M., Yamazaki, F. (2001b) Digital damage detection due to the 1999 Kocaeli, Turkey earthquake, *Bulletin of the Earthquake Resistant Structure Research Center*, 34, 55-66.
13. Estrada, M., Kohiyama, M. and Yamazaki, F. (2001) *Assessment of satellite imagery capability for damage detection using Landsat 7/ETM+ images for the 2001 Atico, Peru earthquake*, http://www.ecie.org/sismoatico/semana1/05/003.pdf.
14. Hasegawa, H., Aoki, H., Yamazaki, F. and Sekimoto, I. (1999) Attempt for automated detection of damaged buildings using aerial HDTV images, *Proceedings of the 20th Asian Conference on Remote Sensing*, Hong Kong.

15. Hasegawa, H., Yamazaki, F., Matsuoka, M. and Seikimoto, I. (2000) Determination of building damage due to earthquakes using aerial television images, *Proceedings of the 12th World Conference on Earthquake Engineering*, Auckland.
16. Hashitera, S., Kohiyama, M., Maki, N. and Fujita, H. (1999) Use of DMSP-OLS images for early identification of impacted areas due to the 1999 Marmara earthquake disaster, *Proceedings of the 20th Asian Conference on Remote Sensing*, Hong Kong.
17. Huyck, C.K. and Adams, B.J. (2002) Emergency Response in the Wake of the World Trade center Attack: The Remote Sensing Perspective, MCEER Special Report Series, Volume 3, MCEER: Buffalo.
18. Huyck, C.K, Mansouri, B., Eguchi, R.T., Houshmand, B., Castner, L. and Shinozuka, M. (2002) Earthquake damage detection algorithms using optical and ERS-SAR satellite data – Application to the August 17, 1999 Marmara, Turkey earthquake, *Proceedings of the 7th U.S. National Conference on Earthquake Engineering*, Boston.
19. Huyck, C.K., Adams, B.J., Cho, S., Eguchi, R.T., Mansouri, B., and Houshmand, B. (2004). Methodology for Post-Earthquake Building Damage Detection using SAR and Optical Remote Sensing: Application to the August 17, 1999 Marmara, Turkey Earthquake, Technical Report MCEER-04-0004, June 15, 2004.
20. Matsuoka, M. and Yamazaki, F. (1998) Identification of damaged areas due to the 1995 Hyogoken-Nanbu earthquake using satellite optical images, *Proceedings of the 19th Asian Conference on Remote Sensing*, Manila.
21. Matsuoka, M and Yamazaki, F. (2000a) Interferometric characterization of areas damaged by the 1995 Kobe earthquake using satellite SAR images, *Proceedings of the 12th World Conference on Earthquake Engineering*, Auckland.
22. Matsuoka, M. and Yamazaki, F. (2000b) Satellite remote sensing of damaged areas sue to the 1995 Kobe earthquake, In Toki, K. (ed.) *Confronting Urban Earthquakes, Report of Fundamental Research on the Mitigation of Urban Disasters Caused by Near-field Earthquakes*, 259-262.
23. Matsuoka, M. and Yamazaki, F. (2002) Application of the damage detection method using SAR intensity images to recent earthquakes, *Proceedings of the IGARSS*, Toronto.
24. Matsuoka, M. and Yamazaki, F. (2003) Application of a methodology for detection building-damage area to recent earthquakes using SAR intensity images, *Proceedings of the 7th EERI US Japan Conference on Urban Earthquake Hazard Reduction*, Maui.
25. Matsuoka, M. and Yamazaki, F. (2004). Use of SAR Intensity Imagery for Earthquake Damage Detection, *Proceedings of the 2nd International Workshop on Remote Sensing for Post-Disaster Response,* Newport Beach, CA, October 7-8, 2004.
26. Mitomi, H., Yamazaki, F. and Matsuoka, M. (2000) Automated detection of building damage due to recent earthquakes using aerial television images, *Proceedings of the 21st Asian Conference on Remote Sensing*, Taipei.
27. Mitomi, H., Matsuoka, M. and Yamazaki, F. (2001) Automated detection of buildings from aerial television images of the 2001 Gujurat, India earthquake, *Proceedings of the IEEE International Symposium on Geoscience and Remote Sensing*, Sydney.
28. Mitomi, H., Matsuoka, M and Yamazaki, F. (2002) Application of automated damage detection of buildings due to earthquakes by panchromatic television images, *Proceedings of the 7th U.S. National Conference on Earthquake Engineering*, Boston.

29. Ogawa, N., Hasegawa, H., Yamazaki, F., Matsuoka, M and Aoki, H. (1999) Earthquake damage survey methods based on airborne HDTV, photography and SAR, *Proceedings of the 5th US Conference on Lifeline Earthquake Engineering, ASCE*, 322-331.
30. Ogawa, N. and Yamazaki, F. (2000) Photo-interpretation of buildings damage due to earthquakes using aerial photographs, *Proceedings of the 12thWorld Conference on Earthquake Engineering*, Auckland.
31. Rathje, E. and M Crawford (2003), Earthquake Damage Identification using High-Resolution Satellite Images from the 2003 Northern Algeria Earthquake, *Workshop on Application of Remote Sensing Technologies for Disaster Response,* Beckman Center, Irvine, September 12, 2003.
32. Rejaie, S.A. and Shinozuka, M. (2001) *Urban damage assessment from remotely sensed images*, http://mceer.buffalo.edu/publications/sp_pubs/01-SP02/sra_ind/08.pdf.
33. Saito, K., Spence, R.J., Going, C. and Markus, M. (2004) Using high-resolution satellite images for post-earthquake building damage assessment: a study following the 26.1.01 Gujurat earthquake, *Earthquake Spectra,* Volume 20: 145-169.
34. Saito, K., and R. Spence, Application of texture analysis to high-resolution optical satellite images for mapping earthquake building damage distribution – a preliminary assessment, *The 2nd International Workshop on Remote Sensing for Post-Disaster Response,* Radisson Hotel Newport Beach, October 7-8, 2004.
35. Yamazaki, F. (2001) Applications of remote sensing and GIS for damage assessment, *Proceedings of the Joint Workshop on Urban Safety Engineering*, Asian Institute of Technology, Bangkok.
36. Yamazaki, F., Matsuoka, M., Yano, Y., Vu, T. Thuy, Kohiyama, M., Kouchi, K. (2004). Visual and Automated Damage Detection for the 2003 Algeria and Bam Earthquakes using High-Resolution Satellite Images, *Proceedings of the 2nd International Workshop on Remote Sensing for Post-Disaster Response,* Newport Beach, CA, October 7-8, 2004.
37. Yusuf, Y., Matsuoka, M. and Yamazaki, F. (2001a) Damage assessment after 2001 Gujurat earthquake using Landsat-7 satellite images, *Journal of the Indian Society of Remote Sensing*, 29(1): 233-239.
38. Yusuf, Y., Matsuoka, M. and Yamazaki, F. (2001b) Damage detection from Landsat-7 satellite images for the 2001 Gujurat, India earthquake, *Proceedings of the 22nd Asian Conference on Remote Sensing*, Singapore.

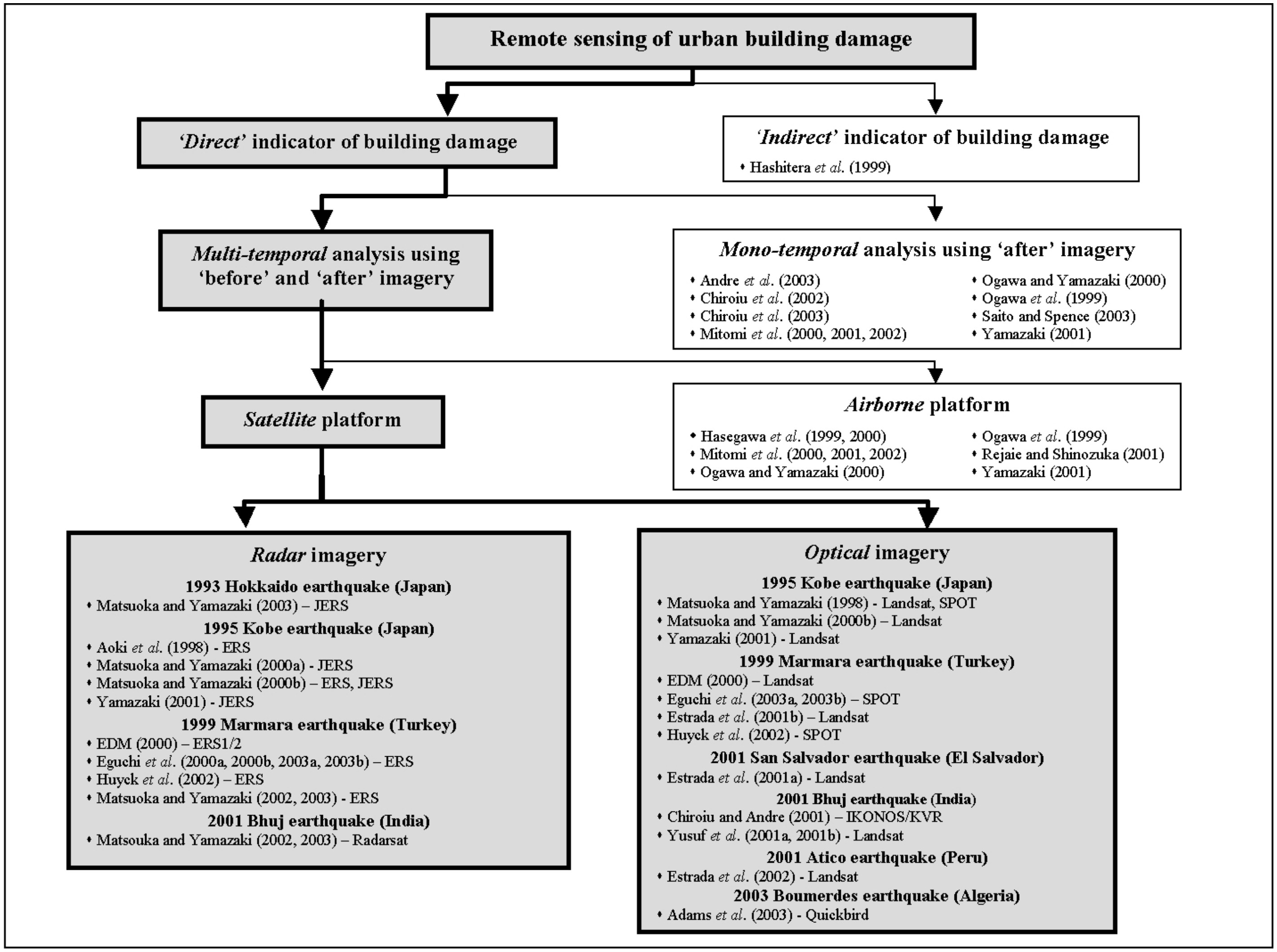

FIGURE 2. Summary of previous research addressing the remote sensing of urban building damage (Huyck, et al., 2004).