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A Summary of Reconnaissance Efforts of the Multidisciplinary Center for Earthquake Engineering Research

MCEER RESPONSE

POST-TSUNAMI URBAN DAMAGE SURVEY IN THAILAND USING THE VIEWS® RECONNAISSANCE SYSTEM

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The Sumatra Earthquake of December 26, 2004, and the tsunamis that it generated, were events of unprecedented magnitude. Because of the number of populated areas that were exposed to the disaster, the immediate and long term effects of the tsunamis are being considered as one of the most significant in the history of mankind. This post-tsunami field campaign, undertaken in some of the hardest hit areas in southwestern Thailand, presented the research team with the unique opportunity to collect perishable damage data, with the aim of increasing the effectiveness of post-disaster damage assessment activities. The data collected will help decision makers better understand the nature and immediate effects of the event, and will support future research to improve disaster response using satellite remote sensing technology. High-resolution satellite images collected before and after the tsunamis were used for the first time to support post-tsunami reconnaissance efforts, and this data may ultimately help develop a preliminary tsunami damage scale.

On December 26, 2004, 00:58:53 UTC, a magnitude 9.0 earthquake occurred off the west coast of northern Sumatra, Indonesia. The epicenter was located beneath the Indian Ocean, at 3.307°N 95.947°E. The earthquake triggered a series of tsunamis in the region that devastated communities along thousands of miles of exposed coastline. Ranked as one of the most catastrophic events in recent times, the earthquake and subsequent tsunami caused significant damage in 11 countries and resulted in over 200,000 deaths. Countless people were rendered homeless, or left without basic lifelines and amenities.

The Multidisciplinary Center for Earthquake Engineering Research joined a multi-lateral Thai-Japanese reconnaissance team to investigate the effects of the tsunami disaster in Thailand. Of the affected nations, Thailand was selected as the destination based on: (1) media reports of destruction at multiple tourist locations, >5,300 deaths, and >US$500 million damage to the nation's shrimp industry; and (2) a preliminary assessment of potential casualties in the region by ImageCat, using remote sensing data.

Figure 1 shows results of the preliminary assessment, using satellite imagery to identify areas of potential devastation. This figure was developed by cross referencing population data from NOAA's (National Oceanic and Atmospheric Administration) DMSP sensor (in yellow and orange) with wave height modeled by Vasily Titov (NOAA, 2005) and proximity to the coastline. The resulting zones of potential damage (in red) were used to prioritize areas for field investigation, and the acquisition of high-resolution satellite images from DigitalGlobe.

The main objective of this post-tsunami field deployment was to collect perishable information about building and lifeline damage characteristics. In the aftermath of a catastrophic event like the Indian Ocean tsunamis, the rapid collection, evaluation, and dissemination of information regarding the spatial extent and severity of damage is of

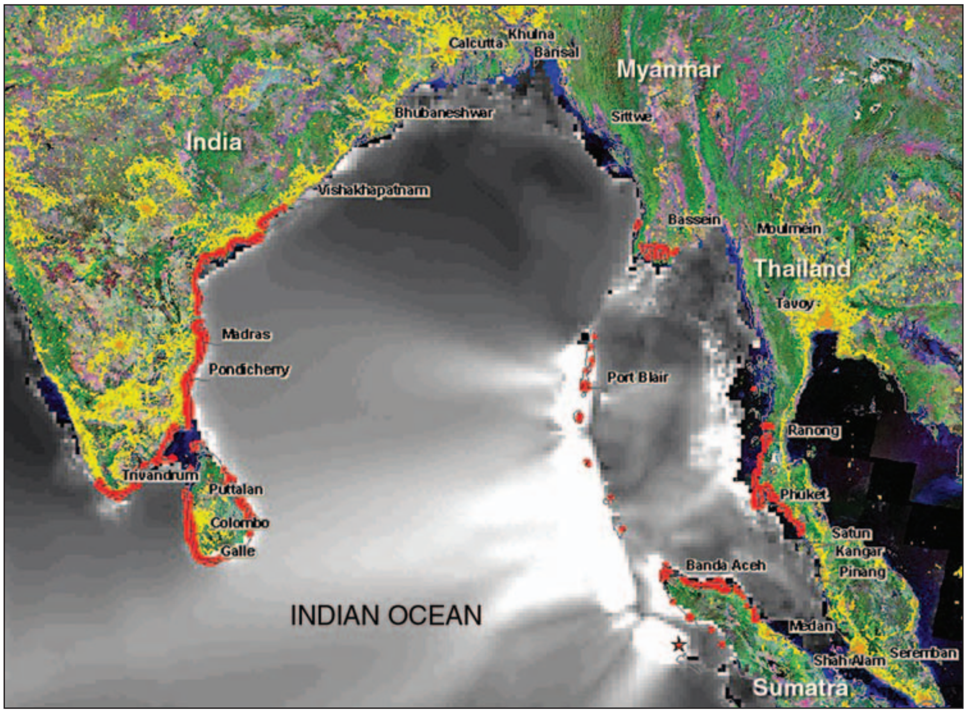

Figure 1. Assessment of potential devastation to coastal populations from the Indian Ocean tsunamis, using satellite imagery. Population data from NOAA's DMSP sensor is shown in yellow and orange. Areas marked in red are zones of potential damage.

critical importance. There is a narrow time window for documenting the building and infrastructure damage from large scale events, as cleanup operations are typically initiated as soon as possible. Traditionally, such damage information is collected through ground-based surveys, whereby damage observations are recorded on hard copy forms and questionnaires (UNESCO, 1998). This process may take weeks or months following the event. However, advanced technologies such as remote sensing and non-traditional survey methods provide rapid data collection and have considerable potential for improving the effectiveness of damage evaluation activities. Accordingly, MCEER funded deployment of the VIEWS (Visualizing the Impacts of Earthquakes With Satellites) system to aid post-disaster field-based damage assessment.

VIEWS is a notebook-based system, which integrates GPS-registered digital video footage, digital photographs and observations with high-resolution satellite imagery collected before and after a disaster. VIEWS was previously used in reconnaissance activities following the 2003 Bam, Iran earthquake (Adams et al., 2004a), Hurricane Charley and Hurricane Ivan that hit Florida's gulf coast in 2004 (Adams et al., 2004b, 2004c), and the Niigata, Japan earthquake in October 2004 (Huyck et al., 2005).

This is the first instance of using the VIEWS system and high-resolution satellite imagery for post-tsunami field reconnaissance. As such, it offered the survey team a unique opportunity to investigate the use of remote sensing for tsunami-related urban damage assessment. It also enabled the survey team to expand the multi-hazard data collection capabilities of the VIEWS system from earthquakes and hurricanes to tsunamis.

To explore new VIEWS functionalities in the tsunami context, two alternative methods for data collection were tested. One approach used an integrated GPS handheld device to track field activities and synchronize the GPS feed with video coverage. The other approach involved the use of three video cameras simultaneously looking in multiple directions (right, left, forward) to record damage information.

All possible types of tsunami-related damage characteristics within residential, commercial, and industrial structures were recorded using VIEWS. The ground-based observations will be used to validate damage characteristics identified on satellite imagery. It is envisioned that such perishable data on damage severity and extent could, in the case of future catastrophic events, be used by key decision makers, emergency response personnel, and researchers for planning response and tsunami mitigation policies.

In summary, three objectives for the post-tsunami reconnaissance mission were identified:

- Collect perishable tsunami damage information
- Explore new VIEWS system functionalities in the tsunami context
- Characterize tsunami damage using remote sensing satellite imagery

This field report documents the post-tsunami damage survey and describes how these three objectives were achieved. It begins with a brief overview of the field study sites and includes a discussion of the satellite imagery and other data that were available from various sources. The report goes on to document damage survey activities that were conducted, together with methodologies employed for data collection. The resulting data sets from the survey are presented. The report summarizes preliminary findings through a selection of illustrative examples, which were extracted using the MCEER funded D-VRS system. Finally, future research is discussed, involving the development of a tsunami damage scale.

SURVEY SITES AND AVAILABLE DATA

The post-tsunami damage assessment was conducted in three areas in southwestern provinces of Thailand (Figure 2):

- Phang Nga
- Phi Phi
- Phuket

In general, survey efforts were focused along a coastal strip approximately 1.5 kilometers wide. Survey site selection was made based on several factors: (1) media reports of areas experiencing severe damage (particularly where the key industries of tourism and fisheries were hard hit); (2) areas for which satellite imagery (Quickbird, IKONOS, Landsat, IRS) were available (see Table 1); and (3) the recommendations of local experts on the survey team. Considerable attention was placed on capturing a broad area for damage assessment, as well as including specific sites such as small bays, stretches of open coast, estuaries, and beaches to document a wide range of tsunami damage.

The field investigation team obtained satellite imagery from multiple sources. The team purchased high-resolution "before" and "after" Quickbird imagery from DigitalGlobe for various coastal areas of Phuket. Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand provided additional IKONOS, IRS, and Landsat datasets in ECW format for visualizing impacts, general navigation, and reference. GISTDA also provided street and province boundary data in shape file format.

Table 1. "Before" and "After" satellite imagery for Thailand.

Satellite Imagery	Date	Time Frame	Area covered	Sources
15m Landsat	8-Apr 2003	Before	Phang Nga, Phi Phi, Phuket	*GISTDA**
60cm Quickbird	23-Mar 2002	Before	Phuket	*DigitalGlobe,USA*
60cm Quickbird	2-Jan 2005	After	Phuket	*DigitalGlobe,USA*
1m IKONOS	29-Dec 2004	After	Phang Nga	*GISTDA*
1m IKONOS	29-Dec 2004	After	Phuket	*GISTDA*
5m IRS	28-Dec 2004	After	Southern Thailand	*GISTDA*

** Geo Informatics and Space Technology Development Agency*

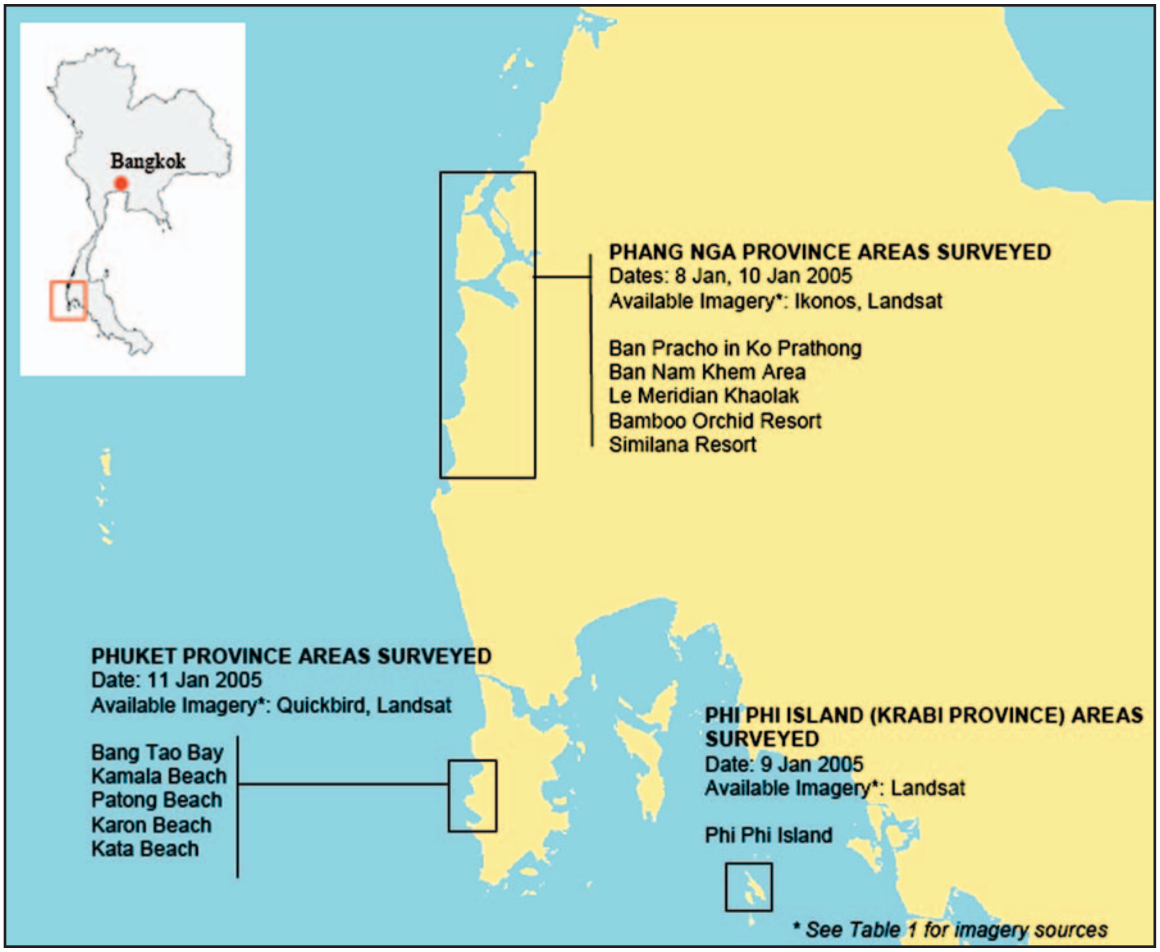

Figure 2. Field survey study areas in Phang Nga, Phi Phi, and Phuket, which sustained heavy tsunami damage.

FIELD DAMAGE SURVEY

Tsunamis with devastating effects like the Indian Ocean event are rare. Since most of the evidence is perishable, it is critical that ground-based observations concerning the damage characteristics of buildings and infrastructure are rapidly collected to capture the nature and extent of the damage. This information provides a basis for validating distinguishable damage characteristics on satellite imagery and will be useful for future tsunami-related research on risk assessment and mitigation.

Traditional methods of post-tsunami reconnaissance survey involve the collection of runup measurements[1], inundation limits[2], and associated data on damage. While conducting walking surveys, general classifications for the nature and category of damage are logged manually on survey forms or tables. Commonly used classifications (see, for example UNESCO, 1998) include: primary nature of damage (wave/water induced), secondary nature of damage (fire, impact, explosion), damage to natural resources (vegetation, trees, coral reefs, etc.), and damage to man-made infrastructure (buildings, roads, lifelines).

The present study is the first time that a non-traditional, technology driven approach has been used to collect field data in the aftermath of a tsunami. The VIEWS system was deployed to streamline the collection of damage-related data and produce a permanent visual record of damage sustained by buildings and other infrastructure for future analysis.

Figure 3 is a screen shot of the VIEWS User interface, showing the coastal area of Phuket in Thailand. High-resolution "before" and "after"

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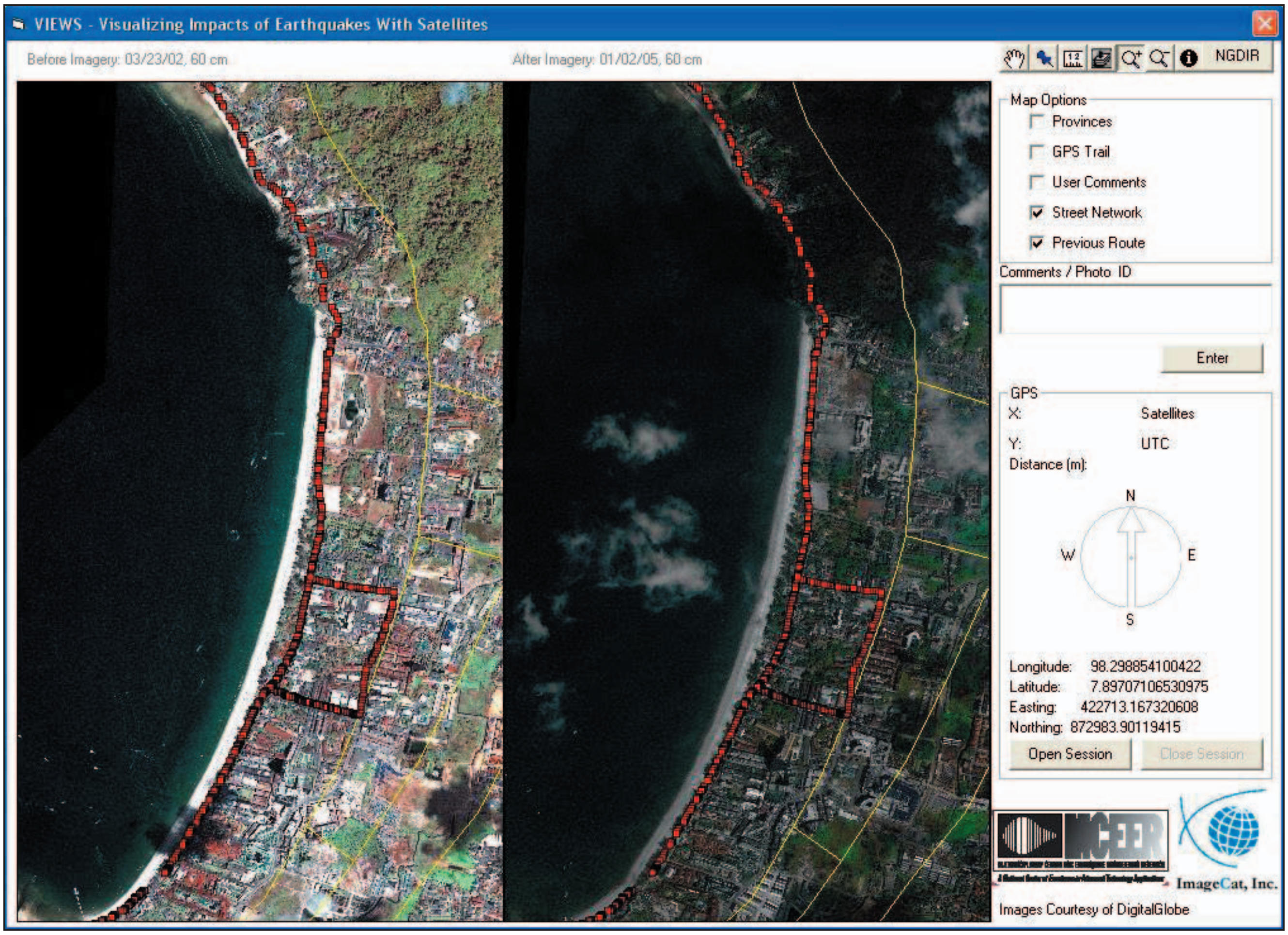
[1] Difference between elevation of maximum horizontal intrusion and sea level at the time of tsunami

[2] Horizontal intrusion of tsunami inland from the sea coast



Before Imagery: 03/23/02, 60 cm

After Imagery: 01/02/05, 60 cm

☐ Provinces
☐ GPS Trail
☐ User Comments
☑ Street Network
☑ Previous Route

X:
Satellites
Y:
UTC
Distance (m):

Longitude: 98.298854100422
Latitude: 7.89707106530975
Easting: 422713.167320608
Northing: 872983.90119415

Images Courtesy of DigitalGlobe

Figure 3. User interface for the VIEWS system, deployed to collect building damage data in coastal Phuket, Thailand.

satellite images serve as the mapping base layer. Through the real-time GPS feed, routes taken around the damaged areas were logged and are overlaid here (in red) on a vector-based street map (in yellow). Georeferenced building damage observations were recorded using the GPS-linked digital video recorder. A georeferenced photographic record was also collected, illustrating tsunami damage characteristics in detail.

The VIEWS damage survey of impacted areas was conducted from either a moving vehicle or on foot, depending on vehicular access. In general, access to selected study areas did not prove to be a significant limitation; admittance to the heavily damaged sites did not require special authorization. However, the areas surveyed within the three provinces were spatially distributed, and traveling to and from the study sites proved to be time consuming. Table 2 provides a breakdown of the daily survey schedule and mode (vehicle or on foot) for the various sites.

The damage survey was conducted from a moving vehicle in areas of Phang Nga (see Figure 4) and Phuket where there was vehicular access to damaged coastal regions. The team selected a van as the optimum type of vehicle, since it provided increased elevation above street level, and better video footage by avoiding obstructions in the foreground. The vehicle was driven at around 10-15 mph, as this speed minimized aberration in the video and stills, while enabling a large geographic area to be covered.

Damage data collection was conducted on foot throughout the three areas of Phang Nga, Phi Phi, and Phuket, where vehicular access was limited (see, for example, Figure 5). On the island of Phi Phi, which suffered extensive building and infrastructure damage, the only possible option for

Table 2. Survey activity schedule, showing the mode of deployment & type of video footage collected.

Date	Areas Covered	Mode of Deployment	Type of Video Footage Collected	Remarks
8-Jan 2005	Phang Nga	Vehicle and on foot	Multiple cameras, Single camera	Some of the coastal resorts surveyed on foot.
9-Jan 2005	Phi Phi	On foot	Multiple cameras, Single camera	No vehicular access on Phi Phi island, surveyed on foot.
10-Jan 2005	Phang Nga	Vehicle and on foot	Multiple cameras, Single camera	Areas of fishing villages surveyed on foot.
11-Jan 2005	Phuket	Vehicle	Single Camera	Unobstructed view of beachfront damage from coastal highway, as such surveyed from vehicle.

VIEWS deployment was on foot. The reconnaissance team surveyed two locations on the island where extreme damage was reported.

For this study, a new approach for data collection was adopted (Figure 6) by deploying three video cameras that simultaneously captured footage from three directions (front, left, and right). This streamlined the video collection process and provided a wider view of the area. The approach of collecting "panoramic" video data was implemented from both the van and on foot, and was used in some of the heavily affected areas of Phang Nga and Phi Phi. An alternative handheld-based approach was also tested for collecting GPS points. A Garmin iQue® Handheld with built-in GPS receiver was used to continuously collect GPS points in the survey sites where VIEWS was deployed.

Eleven hours of georeferenced digital video footage were recorded along the reconnaissance survey route that covered >50 kms. A library of approximately 1,500 spatially-referenced digital photographs was also collected by the team. This data collection effort fulfilled two of the three objectives identified for the post-tsunami field activities i.e., *collecting perishable tsunami damage information* and *exploring new VIEWS system functionalities in the tsunami context*.

CONSIDERATIONS FOR DEPLOYING VIEWS

Customizing the VIEWS system before field deployment for a given disaster requires initial planning and integration of raster (e.g., satellite imagery) and vector (e.g., streets, utility lines) data. Key factors in successful deployment of the VIEWS reconnaissance system include: (1) the quality of base data and the ease of acquiring it; and (2) the expertise and experience of team members.

High-resolution remote sensing satellite imagery used in the VIEWS system was acquired from data providers including DigitalGlobe and Space Imaging. The user has the option of ordering archived imagery or requesting a tasked collection. Data acquisition and processing can take from one day up to a week, depending on the availability of archive material, or the next opportunity of tasked acquisition. Considerations for ordering satellite imagery for damage surveys include:

- Identifying archival datasets of interest, based on potential survey site locations
- Contacting the data provider with the intent of placing an order
- Establishing an area of interest for acquiring the data
- Identifying suitable "before" imagery within the archive, carefully considering image quality parameters, and the date of acquisition
- Requesting that the data provider send notification and an overview image when the first "after" event coverage is acquired
- Placing an order on the day that the "after" imagery becomes available

Vector data such as street layers, political and administrative boundaries, landmark and locations are available through various government and research organizations. The efficient acquisition and integration of these data into VIEWS improves survey navigation, information presentation, and documentation.

In terms of survey team members, experienced participants are needed with multidisciplinary

Figure 4. A selection of routes (red dots) through the Khao Lak area in Phang Nga province along which GPS readings, georeferenced video coverage and photographic record were collected from a moving vehicle, as well as on foot.

Figure 5. An example of a survey location in a heavily damaged Khao Lak resort in Phang Nga where foot based deployment was undertaken. The survey route is depicted by GPS points (red dots) along which georeferenced video and photographs were collected.

(a) VIEWS deployment with one camera

(b) VIEWS deployment with three cameras

Figure 6. Field deployment of the VIEWS system following tsunamis in Thailand, (a) Using a single video camera, and (b) Using multiple video cameras.

backgrounds in geography, land surveying, planning, engineering, public health, community relations, and ideally post-disaster survey. It is highly desirable that at least one of the team members is from the affected country and speaks the local language. Prior to departure from the field, local agencies and experts should be tapped for knowledge and expertise on existing conditions. It is recommended that a survey team deploying the VIEWS system includes 2-3 members.

TSUNAMI DAMAGE VISUALIZATION AND INTERPRETATION

Traditional post-tsunami damage surveys focus on the measurement of runup heights, inundation (distance of horizontal penetration inland), and casualties, including a general classification of damage (UNESCO, 1998). In order to accurately estimate tsunami losses (in terms of dollar cost and casualties) physical parameters, such as wave height, need to be analyzed in conjunction with information about population and infrastructure (see Figure 1). Observations concerning the degree and extent of damage are also key in estimating losses for a particular event, since they provide a basis for developing vulnerability functions. Ground-based observations, together with satellite remote sensing technology, provide an effective way to investigate post-tsunami urban damage.

To support the visualization, interpretation, and analysis of post-disaster field data collected using VIEWS, MCEER funded the development of a desktop "virtual reconnaissance system," referred to as D-VRS. Figure 7 shows a "screen grab" from D-VRS, which provides researchers with easy access to the satellite imagery, GPS readings, and georeferenced video and photographic records for the survey sites. The user has an option to toggle between multi-temporal and multi-source satellite images, and to explore the images in detail using zoom and pan functions. The imagery is overlaid with GPS routes collected during the survey. By selecting a GPS point, the user can view corresponding video footage and scroll through the photographic archive, in the adjacent windows. The photographic library can be augmented with stills captured directly from the video as it plays, each of which is output to a new georeferenced file.

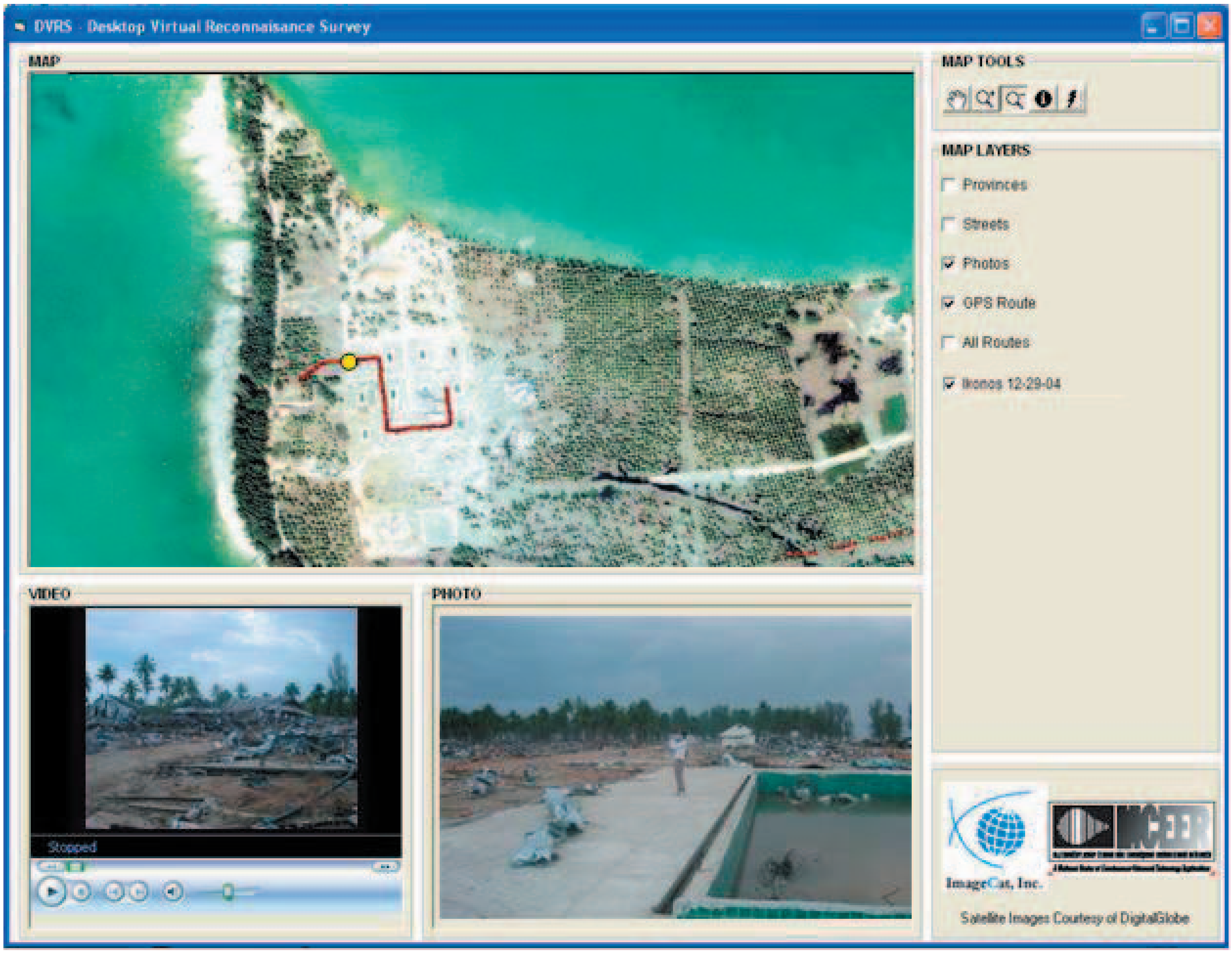
The following examples in Figure 8 show tsunami damage footage collected together with "after" satellite coverage. The areas studied included tourist resorts (Phang Nga, Phi Phi, Phuket) and fisherman's villages (Phang Nga) along the coast. Structures in these areas were mostly commercial or residential. In addition, there were some commercial structures for the shrimp industry and a few government buildings.

In general, for commercial structures, all levels of damage were observed, ranging from completely damaged resort buildings, shopping structures, and shrimp farms, through moderately damaged buildings, to minimal damage to resorts and shop fronts (nonstructural damage to windows, building facade, etc.) and complete loss of building contents.

As shown in Figure 8(a) and 8(b), commercial structures in Phang Nga (Khao Lak area) were among the hardest hit due to the area's long and narrow stretch of exposed coastline. NOAA reported these areas recorded tsunami wave heights of up to 11 meters. Most of the resorts surveyed sustained heavy to complete damage. Phi Phi Island hotels and resorts were also among the worst affected with most resorts in Ton Sai Bay closed in the aftermath of the huge waves that swept across the island. Damage to commercial structures in Phuket was mixed, ranging from extensive to minor or no damage.

Residential structures in the fisherman's villages studied in Phang Nga sustained the most damage. Some of the residential areas were completely wiped out or were turned into piles of debris. Both masonry and reinforced concrete (RC) residential buildings suffered heavy damage. Masonry structures for shrimp farming along the coast were also destroyed completely. Most small boats were damaged, moved ashore, or crashed into each other as evidenced from the survey.

From a remote sensing perspective, Figure 9 illustrates the importance of acquiring both pre-event and post-event satellite imagery. It becomes easier to determine the extent of damage or change when compared with the non-damage scenario. Using the D-VRS system and Quickbird imagery, the following damage related observations can be made for Phuket:



☐ Provinces
☐ Streets
☑ Photos
☑ GPS Route
☐ All Routes
☑ Ikonos 12-29-04

Figure 7. Screen shot from the D-VRS virtual reconnaissance system, showing satellite imagery, GPS readings, video footage and digital photographs collected in Khao Lak, Thailand.

IKONOS image, courtesy GISTDA, 12/29/04

QUICKBIRD image, courtesy Digital Globe, 1/5/05

IKONOS image, courtesy GISTDA, 12/29/04

Figure 8. Tsunami damage photos of commercial/government structures in Phang Nga: (a) Completely destroyed Bamboo Orchid Resort; (b) Heavily damaged Similana resort; (c) Heavily damaged Phang Nga government building.

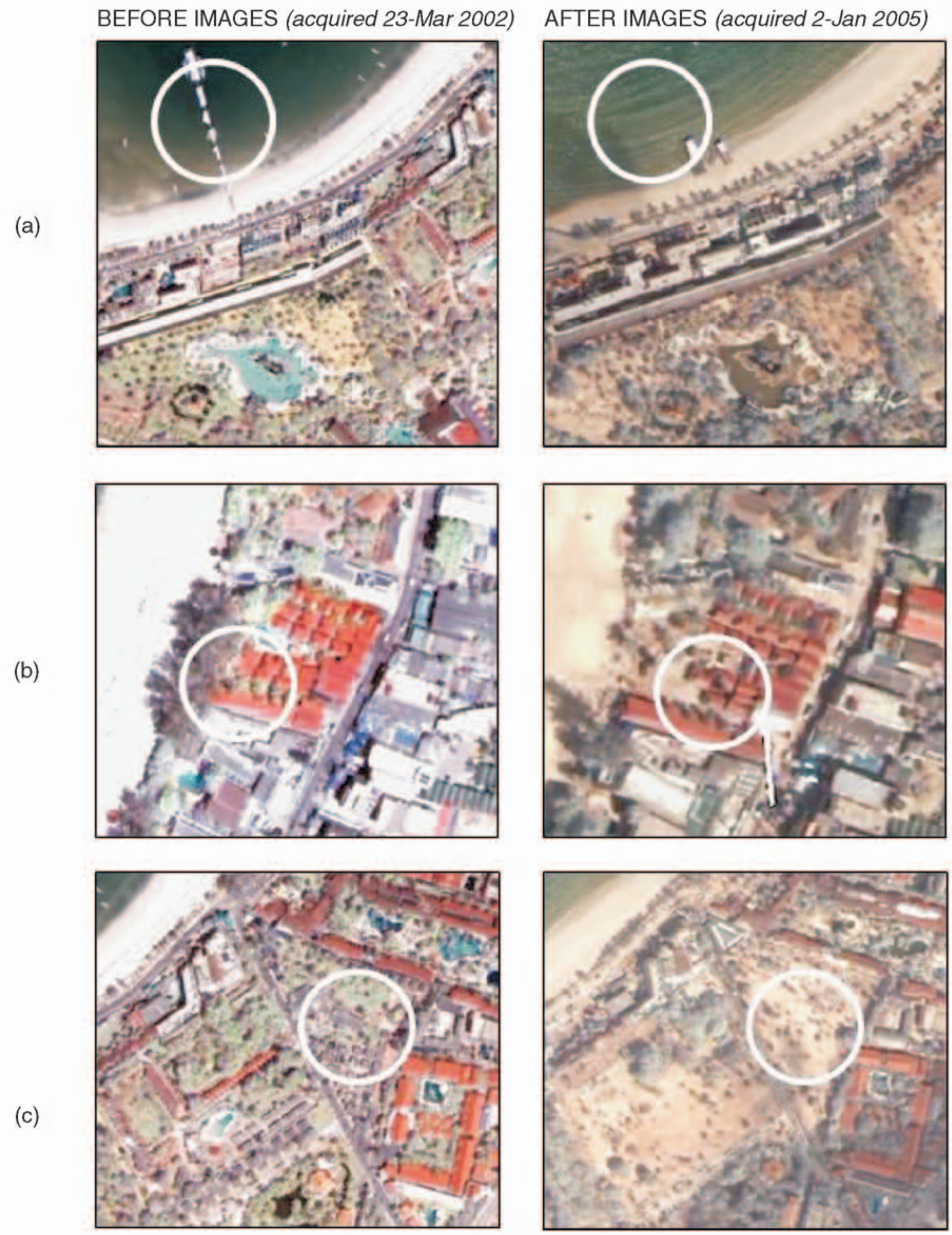


Figure 9. Selected examples of pre-event and post-event satellite imagery for Phuket: (a) Changes in color of water in water bodies and missing pier in after image; (b) Beach front damage to hotel units in after image; (c) Major change in urban development (it is difficult to infer whether this is due to tsunami damage or cleared for urban re-development due to the large difference in acquisition date between" before" and "after" images).

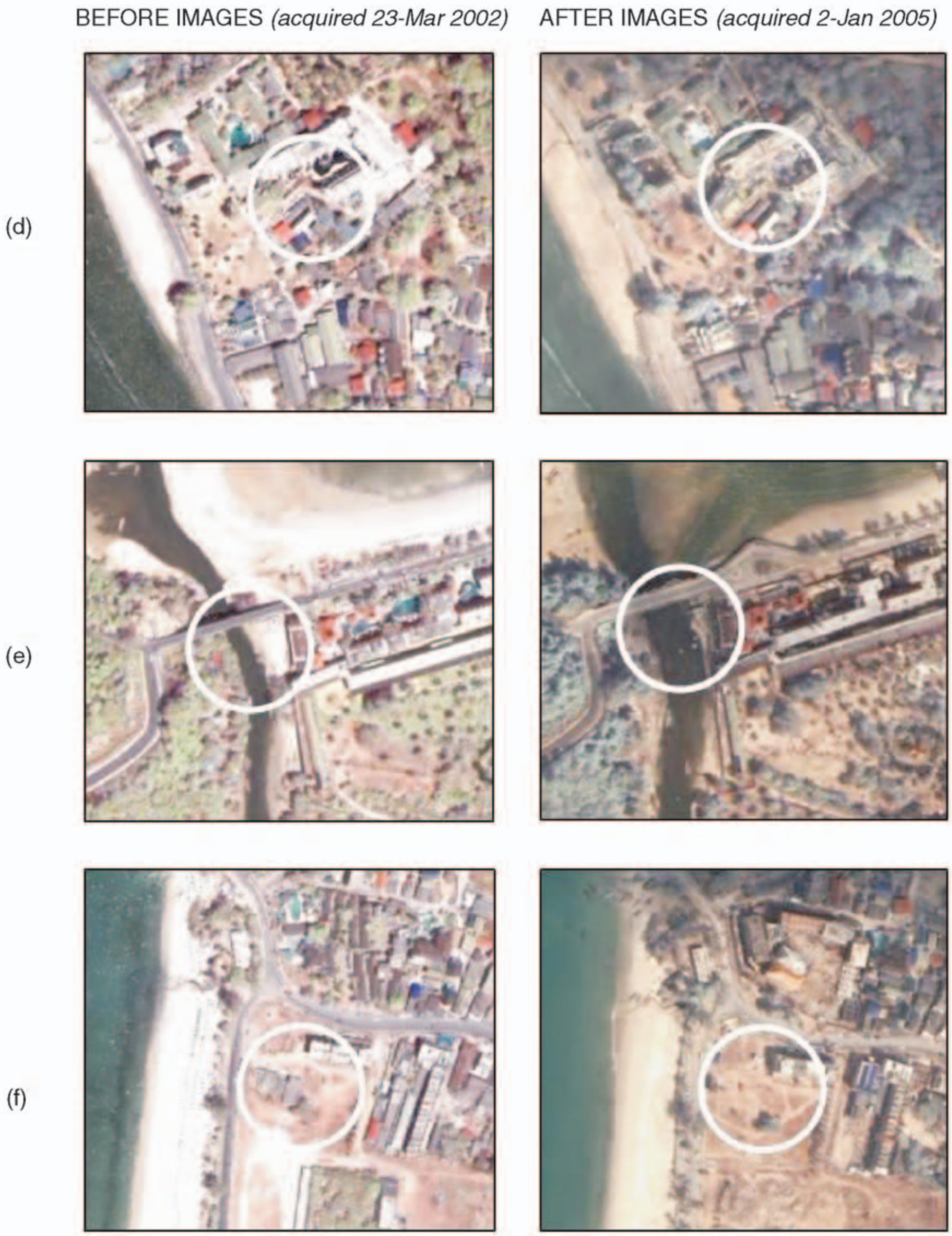
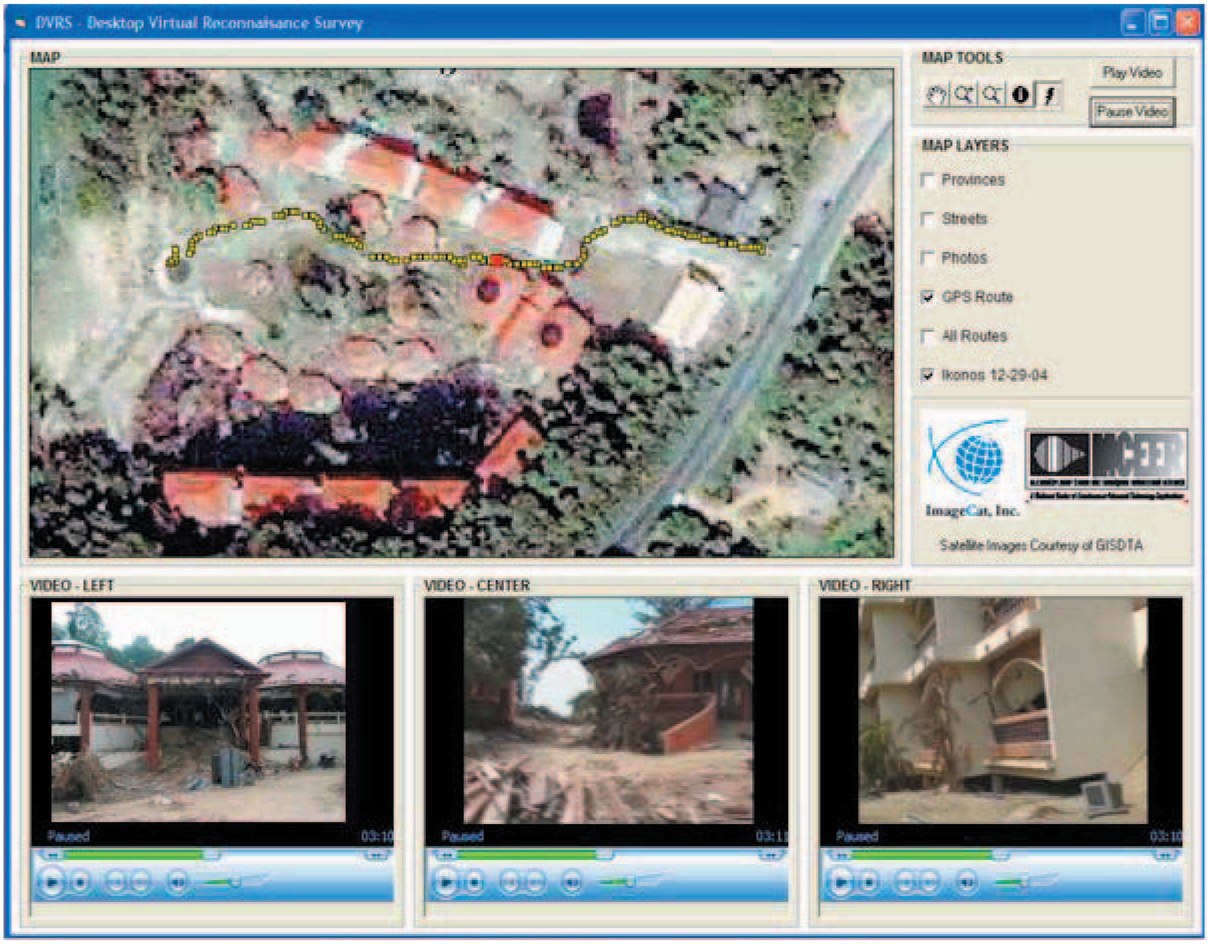


Figure 9 (continued). Selected examples of pre-event and post-event satellite imagery for Phuket: (d) Debris evident in hotel complex; (e) Changes in beach and stream configuration in after image; (f) Major change in urban development (it is difficult to infer whether this is due to tsunami damage or cleared for urban re-development due to the large difference in acquisition date between "before" and "after" images).

- Wash-over of sea water has filled swimming pools and other water bodies in many areas. These look murky green rather than blue [see Figure 9(a)].
- A pier in the "before" imagery has been washed away in "after" imagery [see Figure 9(a)].
- Wash-over of sand has caused a change in road color from grey to brown [see Figure 9(b), 9(c), 9(d)].
- Beach front damage to hotel units. Some are completely destroyed. [see Figure 9(b)].
- Major change in urban development. In some cases, it is difficult to infer whether this is due to tsunami damage or cleared for urban re-development due to the large difference in the acquisition date between "before" and "after" images [see Figure 9(c) and 9(f)].
- Debris evident in hotel complexes in coastal areas [see Figure 9(d)]
- Change in beach and stream configuration [see Figure 9(e)].

These observations present a preliminary step towards fulfilling the third objective of this report, i.e., *characterizing tsunami damage using high-resolution remote sensing satellite imagery.* In terms of future research, the data collected could be used to characterize damage to buildings by classifying levels of damage. In an applied sense, it could also be used to establish the extent of damage for estimating regional losses. However, the nature of data collected using the VIEWS system and visualized and interpreted using the D-VRS system does not, at this time, provide physical measurements (e.g., runups, inundation



☐ Provinces
☐ Streets
☐ Photos
☑ GPS Route
☐ All Routes
☑ Ikonos 12-29-04

IKONOS image, courtesy GISTDA, 12/29/04

Figure 10. Screen shot from the D-VRS virtual reconnaissance system, showing satellite imagery, GPS readings, and video footage from three video cameras collected in Phang Nga, Thailand.

limits) as in the case of a traditional post-tsunami survey (although visual records of watermarks were collected, wherever possible, throughout this survey).

MULTI-DIRECTIONAL D-VRS

In addition to the uni-directional visualization for this study, a multi-look angle version of the D-VRS interface was developed. From Figure 10 (see page 13), three windows (front, left, and right) play video footage from the three cameras that were simultaneously deployed within heavily affected areas. This video collection and visualization process provides an enhanced field of view.

FUTURE WORK: A TSUNAMI DAMAGE SCALE

Remote sensing technology offers immense potential for rapid post-tsunami loss estimation, both through direct observations of damage across a broad geographic extent, and indirectly using predictive models (see, for example, Figure 1) and loss estimation tools. A comprehensive urban damage scale for tsunamis underpins the direct and indirect quantification of losses. In the immediate aftermath of a disaster, quickly and accurately establishing the extent and severity of damage minimizes loss and human suffering. Standardized damage measures also provide the basis for developing vulnerability curves, a key component of loss estimation models that links hazard and exposure with human and economic costs.

The literature documents a number of tsunami damage scales. The Sieberg-Ambraseys scale (Ambraseys, 1962) describes tsunami damage using six levels (Table 3). The expanded 2001 tsunami intensity scale published by Papadopoulos and Imamura (2001), instead employs twelve

Table 3. Urban tsunami damage scales documented in the literature.

Sieberg-Ambraseys (Ambraseys, 1962) Scale		**Papadopoulos and Imamura (2001) Scale[1]**	
Damage Level	**Description of Urban Damage**	**Damage Level**	**Description of Urban Damage**
1	None	1	None
2	None	2	None
3	Slight damage to light structures situated near the coasts.	3	None
4	Light scouring on man-made ground. Embankments and dikes damaged. Light structures near the coasts damaged. Solid structures on the coast injured.	4	None
5	Quay-walls and solid structures near the sea damaged. Light structures destroyed. Harbor works damaged. People drowned.	5	Limited flooding of outdoor facilities (e.g., gardens) of near-shore structures.
6	Partial or complete destruction of manmade structures for some distance from the shore. Trees uprooted or broken. Many casualties.	6	Damage and flooding in a few wooden structures.
		7	Many wooden structures damaged, few are demolished or washed away. Damage of grade 1 or flooding in a few masonry buildings.
		8	Most wooden structures are washed away or demolished. Damage of grade 2 in a few masonry buildings. Most RC buildings sustain damage, in a few damage of grade 1 and flooding is observed.
		9	Damage of grade 3 in many masonry buildings, few RC buildings suffer from damage grade 2.
		10	Damage of grade 4 in many masonry buildings, few RC buildings suffer from damage grade 3. Artificial embankments collapse, port water breaks damaged.
		11	Damage of grade 5 in many masonry buildings, few RC buildings suffer from damage grade 4, many suffer from damage grade 3.
		12	Practically all masonry buildings demolished. Most RC buildings suffer from at least damage grade 3.

[1] *The twelve divisions in the Papadopoulos and Imamura (2001) scale is consistent with the twelve-grade seismic-intensity scales used extensively in Europe and North America*

levels. In both cases, building damage is described qualitatively, employing terminology such as ‘light structures are destroyed’ and ‘limited flooding of outdoor facilities of near-shore structures’ (see Table 3). Papadopoulos and Imamura (2001) distinguish between structural types such as wood frame and masonry. No obvious distinction is made between occupancy types.

Observations captured using satellite imagery and ground-based surveys constitute a valuable resource for extending scientific understanding of post-tsunami urban damage. The Indian Ocean event presents an opportunity to augment existing damage scales. Based on experience from the earthquake and hurricane research arenas (see, for example, Adams et al., 2004a, 2004b, 2004c, Huyck et al., 2005), potential improvements could include:

- Extension of existing damage measures to include new descriptors
- Supplementation of qualitative damage scales with quantitative measures
- Development of automated damage assessment algorithms
- Formulation of discrete damage scales as a function of structural type or occupancy

Future damage assessment research activities should also explore the use of remote sensing techniques for modeling hazard and exposure.

ACKNOWLEDGEMENTS

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