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GOOGLE EARTH MAPPING OF DAMAGE FROM THE NIIGATA-KEN-CHUETSU M6.6 EARTHQUAKE OF 16 JULY 2007

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ABSTRACT

We describe the use of Google Earth during and after a large damaging earthquake that struck the central Japan coast on 16 July 2007 to collect and organize damage information and guide the reconnaissance activities. This software enabled greater real-time collaboration among scientists and engineers. After the field investigation, the Google Earth map is used as a final reporting product that was directly linked to the more traditional research report document. Finally, we analyze the use of the software within the context of a post-disaster reconnaissance investigation, and link it to student use of Google Earth in field situations.

INTRODUCTION

The earth science and earthquake engineering community develops reliability models for the survivability of structures and ground types subjected to transient loading such as seismic and wind forces. Survivability refers to a structure or ground type as having the capacity to absorb loads and maintain integrity within an acceptable level of deformation. Sophisticated theoretical and numerical models are used to assess survivability, and these models need ground-truth evaluations (extreme events like earthquakes and storms) to test their ability to predict damage potential. For that reason, data collection of damage aspects after large events such as earthquakes and storms is critical for model evaluation. The U.S. National Science Foundation, the American Society of Civil engineers, and the U.S Geological Survey routinely dispatch reconnaissance teams to the mesoseismal regions of damaging earthquakes to document the damage aspects of the event. Reconnaissance visits have served an important role in earthquake engineering research and have led to significant advancements in our understanding of structural and ground failures (e.g., failure of steel, reinforced concrete, masonry, and wood frame structures; landslides, and soil liquefaction); amplification effects of seismic waves at the ground surface due to soil properties; performance of improved engineered ground; and the seismic behavior of dams and other earth structures. Traditionally, reconnaissance teams have collected data and documented observations using conventional data recording and measurement tools such as photography, note taking, and surveying [Kayen et al., 2004].

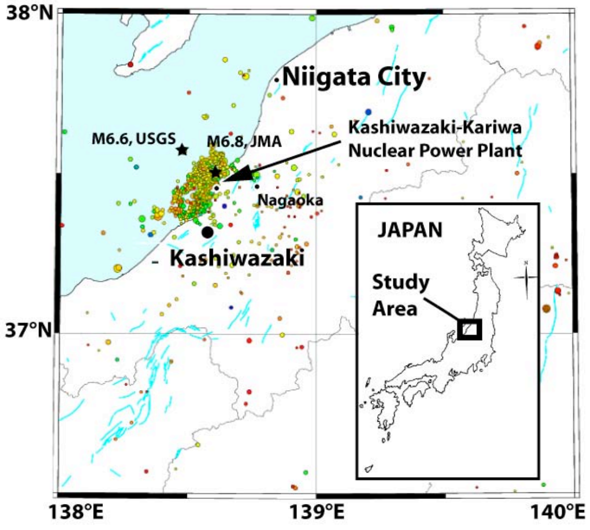


Figure 1. Main shock and aftershock pattern of the 16 July 2007 Niigata Chuetsu Oki, Japan, Earthquake.

Development of advanced technologies such as dynamic Internet-based mapping techniques, remote sensing, and digital imaging now offer the opportunity to visualize and dramatically improve both the quality and quantity of data collected during earthquake reconnaissance investigations. In addition, theses technologies allows for real-time spatial analysis of damage patterns that can be used to identify areas of high and anomalous damage potential. These technologies allow the earth science and engineering community to draw on the full depth of the data collection and contribute to the analysis.

NIIGATA, JAPAN, EARTHQUAKE OF 16 JULY 2007

The M6.6 mainshock of the Niigata Chuetsu Oki earthquake occurred offshore the cities of Kashiwazaki and Kariwa, Japan, at 10:13 a.m. local time on July 16, 2007, and was followed by a sequence of strong aftershocks. The mainshock had an estimated focal depth of 10 km (USGS, 2007) and struck in the Japan Sea. The quake affected an approximately 100-km-wide area along the coastal areas of southwestern Niigata prefecture.

The earthquake resulted in eleven fatalities and nearly two thousand injuries. Over 1,100 collapses of residential structures took place, mostly in old houses with wood and clay walls and heavy kawara, clay-tile roofs. Damage occurred in lifeline utilities of gas, water, sewage, storm drain and electricity. Electric power generation recovered in areas without downed power lines within a day in most of the epicentral area. However, the water supply system and gas network were also damaged in areas of soft ground and in some areas of the city these services still were not available 1.5 months after the event.

Figure 2. Reconnaissance Team members Scott Brandenberg (UCLA) and Brian Collins (USGS) recording damage observations for Google Earth and web report.

Strong motion instrumentation in Kashiwazaki city recorded an extremely high value of peak ground acceleration of 0.67g.). In the neighboring village of Kariwa, home to the world's largest nuclear power plant with seven reactors and a total output of 8200 megawatts, high seismic intensity was also recorded. This facility is located above the ruptured fault plane and underwent recorded instrumental accelerations at the floor level of the reactors ranging from 0.32 g to 0.68 g, and exceeding 1.0 g on the roof of reactor buildings and the top of the turbine structures. (A detailed 230 page report of this earthquake investigation can be found http://pubs.usgs.gov/of/2007/1365/)

RECONNAISSANCE METHODS

The initial reconnaissance of the earthquake was a combined effort of the United States (US)-based Earthquake Engineering Research Institute (EERI), and the Geo-Engineering Earthquake Reconnaissance (GEER) Activity of the US National Science Foundation (US NSF) with assistance from the US Nuclear Regulatory Agency (NRC) and the US Geological Survey (USGS). The investigation was led by the first author, who travelled with the first reconnaissance team to Niigata, Japan within three days of the earthquake. Numerous follow-on teams, consisting of both US and Japanese collegues participated in the study to characterize specific damage aspects of the event, particularly to assess the impact of the earthquake on the nuclear power plant.

The purpose of organizing investigations so rapidly after an extreme event is to document the engineering and scientific effects to advance research and practice. In the Japanese earthquake, the team's main goal was to quantify the spatial extent and amplitude of structural and ground failures, soil liquefaction, landslides, and damage to bridges, piers, ports and harbors, lifeline systems and critical facilities like the nuclear power plant. Data for these studies is extremely perishable, due to the necessary follow-on recovery and reconstruction activities. Toward that end, we develop a coordinated and rapid response for geoengineers and earth scientists so as to avoid self-assembled, less-effective, post-earthquake reconnaissance efforts. In addition, the findings of post-event investigations must be disseminated in a timely and accurate manner, initially in the form of post-earthquake web-based reports and data sets that are accessible to the entire earthquake community. Another aspect of a multi-agency coordinated study is to promote the standardization of measurement and reporting in reconnaissance efforts.

There is also an educational aspect of these activities, as they bring together new faculty and graduate students in the field with experts who have the experience of participating and leading numerous post-event investigations. This is done to advance the capabilities of individuals performing post-earthquake reconnaissance and prepare the next generation of earthquake engineers and scientists.

As such, the training of technical skills to perform effective post-earthquake investigations is critically important. Members of these studies are committed to increasing seismic safety through the collection, documentation, analysis, and dissemination of post-earthquake engineering measurements and information. Anyone who serves on post-earthquake reconnaissance efforts that are funded in part by the National Science Foundation agrees to make their collected data available conveniently and rapidly to the engineering and scientific research and practicing professional community.

GOOGLE EARTH IN POST-DISASTER STUDIES

The advent of new and innovative technologies for post-earthquake reconnaissance is such that on these investigations we are always testing new methods, sensors, and systems to improve data collection, particularly in the realm of spatial information tools. During this earthquake investigation, we explored a promising technology in disaster reconnaissance studies, Google Earth, a mapping software tool that allows for detailed data, imagery and hyperlinked overlays, as well as traditional geographic information system tools. In this paper we describe the real-time application of this program in the field during the collection and organization of earthquake damage data in the form of geographic coordinates, text, imagery and field measurements, and the use of the program to guide the reconnaissance activities.

Google Earth is a software product that allows for viewing of Earth satellite imagery, maps and user defined overlays of geographic information. Paid versions of the software (Google Earth-Plus, -Pro, and –Enterprise) allow for varying degrees of ability to overlay and control data including GPS device input of data and the creation of data layers.

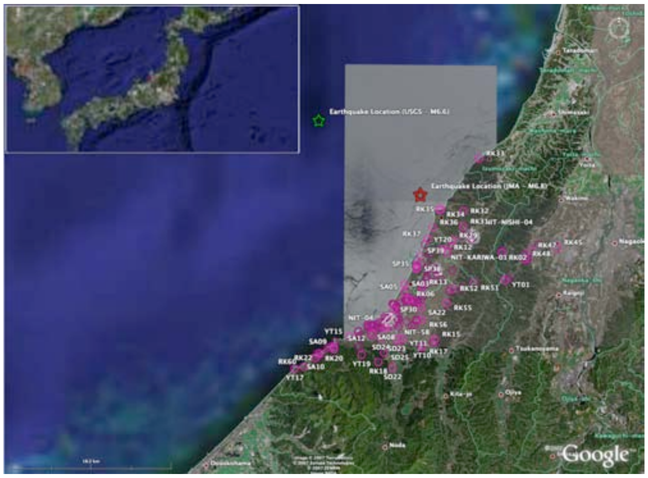


Figure 3. Google Earth Map of all sites in the Niigata-Chuetsu Japan earthquake reconnaissance area

After the Niigata earthquake, and prior to the field reconnaissance, the Google Earth Pro version of the software was loaded onto a laptop computer. In the software preferences, the cache was set to the maximum stetting (2GB) and the study area in Niigata was viewed in detail. Then the program was turned off. This allowed the last images cached on the hard disk to be accessible when the computer was in the field in the epicentral area with no Internet connection. Near the Kashiwazaki-Kariwa Nuclear Power Plant and the surrounding areas, we could then use the program to annotate the map with locations of varied damage aspects and intensities. As the map was populated with observations it became the primary tool for planning each day's studies.

During the length of the study, in late July and early August of 2007, vehicles were used to cover most of the road network of the epicentral region. Each of the vehicles had teams equipped with hand-held two-way radios, telephones, digital cameras, digital and paper maps, computers for recording site logs, and GPS units for recording track logs and site locations. In the evening, the reconnaissance team held clearinghouse meetings where the GPS data, digital site logs and digital pictures were merged into a spreadsheet. At these meetings, we generated Google Earth (.kml mark-up language) files to display all of the written observations on dynamic digital maps (Figure 3), and damage-specific maps. By observing the extent of the damage in Google Earth, we identified unexplored areas for the next days reconnaissance, as well as spatial trends in the damage observations, and any errors in the GPS logs and hand-typed observations. The .kml files were also sent by email to the United States so that the US NSF sponsoring organizations, EERI and GEER, could participate on the reconnaissance effort by taking virtual tours of the damage zone, and assisting in the planning of follow-on reconnaissance efforts; in the past we would have sent digital photos by email to individual researchers in these organizations, and composed reports using Microsoft PowerPoint which would include fairly crude maps.

Using the Google Earth 3D display of buildings and residences for the city of Kashiwazaki enabled us to identify the locations of critical facilities such as the waste-water plants, municipal waste incinerators, schools, and other municipal buildings for inspection.

The program allowed us to link a map, symbols, damage aspects as text, location data, and photos, as well as LIDAR (Light Detecting And Ranging, an optical remote sensing technology) images and movies. The symbols were useful for the collapse data and epicenter locations.

After the earthquake reconnaissance, we found through an evaluation of our procedures that using three relatable spreadsheets provided better flexibility in producing the kmz file than the single large spreadsheet we used in the field. The three spreadsheets are

1) Location, that includes Site ID, Latitude, Longitude; 2) Photos, that includes Site ID, Absolute Pathname (a URL network linkage to the photos that removes the necessity of hosting all the photos on one server); and 3) Observations, that includes Site ID and 22 possible observation categories (e.g., Liquefaction, Lateral Spreading, Ground Settlement, Landslide, Road Embankment Failure, Pavement Failure, Railway Deformation, Bridge Approach Offset, Bridge Bearing Offset, Toppled Monument, Fine-Grained Soil Failure Structural Settlement, Severe Structural Damage, Moderate Structural Damage, Minor Structural Damage. No Structural Damage, Retaining Wall Deformation, % Red Tag Structures, Business Continuity and Industrial Facility, Structure & Ground Interaction, Collapse Direction). The spreadsheets were saved as tab delimited files and an in-house Fortran program 'sites4kml.for' was used to merge the data from these three files into the Google Earth ready kml file.

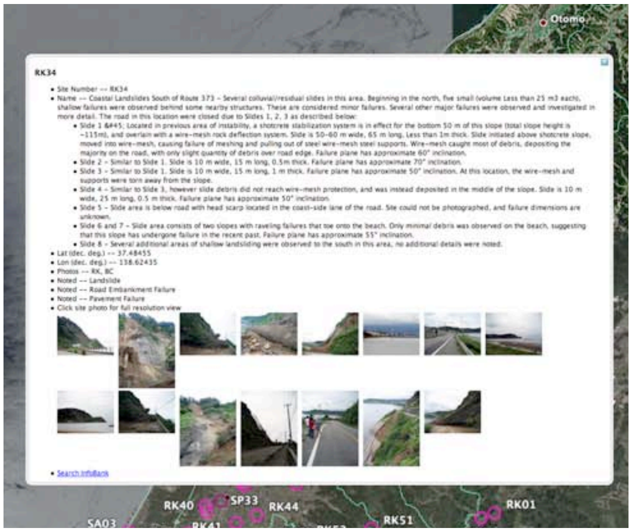
GOOGLE EARTH MAP FEATURES

The general site map of the reconnaissance area (Figure 3) is populated by several symbol types. Two epicenters (USGS and JMA) are determined with different data sets and posted as green and red stars respectively. Clicking on the stars opens a dialog box with detailed information about the earthquake magnitude, mechanism, and timing. The other sites are posted as sites visited (circles) or collapsed structures (arrows), along with the site identifier. The identifier is a combination of the initials of the observer team and the chronological order of the observation (e.g., YT20 was observed by the vehicle-team led by Yasuo Tanaka, and is their twentieth site formally logged). Double clicking on the symbols will let the viewer fly to the site, and single clicking opens up an information balloon.

In Figure 4, the information balloon can be seen pointing to a site that experienced multiple-landslide damage. The balloon lists the site identifier, a paragraph detailing the observed damage, the geographic coordinates of the site, and a suite of small 100-200 pixel thumbnail images. Each thumbnail is linked to its corresponding full resolution image.

One aspect of Google Earth is the ability to segregate the data using radio buttons. In the 'places' folder of the left sidebar is a list of the sites. Choosing 'All Sites' selects all of the locations in the .kml file. Damage aspect specific sites can be selected as well. A researcher interested in studying sites of bridge and bridge approach damage can select the appropriate radio button and filter only those relevant sites. We listed twenty radio buttons to select either all of the data, or damage specific data. This is a powerful tool as some of the sites have multiple damage aspects and prior to the use of Google Earth could not be easily cross-referenced in a visual manner.

Figure 4. Example of balloon text and imagery box in the Google Earth map. Note spatial relation of liquefaction-related lateral spread sites to their proximity to the Sabaishi River.



RK34

- Site Number --- RK34
- Name --- Coastal Landslides South of Route 373 - Several colluvial/residual slides in this area. Beginning in the north, five small (volume Less than 25 m3 each), shallow failures were observed behind some nearby structures. These are considered minor failures. Several other major failures were observed and investigated in more detail. The road in this location were closed due to Slides 1, 2, 3 as described below:
    - Slide 1 - Located in previous area of instability, a shotcrete stabilization system is in effect for the bottom 50 m of this slope (total slope height is ~115m), and overlain with a wire-mesh rock deflection system. Slide is 50-60 m wide, 65 m long, Less than 1m thick. Slide initiated above shotcrete slope, moved into wire-mesh, causing failure of meshing and pulling out of steel wire-mesh steel supports. Wire-mesh caught most of debris, depositing the majority on the road, with only slight quantity of debris over road edge. Failure plane has approximate 60° inclination.
    - Slide 2 - Similar to Slide 1. Slide is 10 m wide, 15 m long, 0.5m thick. Failure plane has approximate 70° inclination.
    - Slide 3 - Similar to Slide 1. Slide is 10 m wide, 15 m long, 1 m thick. Failure plane has approximate 50° inclination. At this location, the wire-mesh and supports were torn away from the slope.
    - Slide 4 - Similar to Slide 3, however slide debris did not reach wire-mesh protection, and was instead deposited in the middle of the slope. Slide is 10 m wide, 25 m long, 0.5 m thick. Failure plane has approximate 50° inclination.
    - Slide 5 - Slide area is below road with head scarp located in the coast-side lane of the road. Site could not be photographed, and failure dimensions are unknown.
    - Slide 6 and 7 - Slide area consists of two slopes with raveling failures that toe onto the beach. Only minimal debris was observed on the beach, suggesting that this slope has undergone failure in the recent past. Failure plane has approximate 55° inclination.
    - Slide 8 - Several additional areas of shallow landsliding were observed to the south in this area, no additional details were noted.
- Lat (dec. deg.) --- 37.48455
- Lon (dec. deg.) --- 138.62435
- Photos --- RK, BC
- Noted --- Landslide
- Noted --- Road Embankment Failure
- Noted --- Pavement Failure
- Click site photo for full resolution view

Figure 5. Detail of thumbnails of damage imagery and damage observations for a landslide damaged site.

The program is also useful as a research tool for identifying spatial patterns of damage, and directional aspects of structural failures. In the first instance, some of the damage patterns are related to specific vulnerable geologic units. Clicking on 'Lateral Spreads' or 'Liquefaction', two cases of earthquake-induced ground failure that effect young loose deposits of sandy material, brings up spatially clustered damage sites. Lateral spreading is a type of landslide that occurs in liquefied ground: liquefaction is the rapid rise of pore fluid pressure between soil grains and the corresponding loss of strength that can happen in soil during an earthquake (Figure 4). The majority of these locations appear to be situated on the banks of two main rivers that cross the city of Kashiwazaki. Further, it can be seen the damage appears to be more spatially extensive and severe along the river-bank closer to the epicenter of the earthquake, and occurs primarily near the river mouth at the Sea of Japan. In these areas the riverbank deposits are sandy and the proximity to the fault rupture elevates the loading cycles of strong motion to a critical level that would trigger these damage types. On the other hand, upriver areas appear to be less susceptible to this damage, even in cases when the river is closer to the epicenter. These areas are composed primarily of clay and silt, and as can be seen in the mapped data, are intrinsically far less susceptible to liquefaction and lateral spreading than are sand deposits.

House tilt and collapse data were given special treatment in the Google Earth presentation. Nagoya Institute of Technology cataloged several hundred structures that suffered racking (tilt) or collapse. Along with the details of the failures, the team recorded the compass direction (azimuth) of the failure. We used the direction data to specify the icon used in the map, and thereby plotted arrows of failure in the direction of collapse. As an example, if the reader clicked on the site NIT-55, in the 'NIT-Niigata Survey' folder in 'Places' a vector pointing west-northwest is shown on the map. This structure, an old style residence collapsed towards the azimuth 292 degrees, probably under the load of strong eastward acceleration pulse. Similar directions of collapse can be seen throughout the neighborhood in Figure 6.


NIT-55

- Site Number -- NIT-55
- Name --
- Lat (dec. deg.) -- 37.37121
- Lon (dec. deg.) -- 138.55986
- Photos -- SP
- Collapse Direction -- 292.5
- Click site photo for full resolution view
- Search InfoBank

Figure 6. Detail of house collapse at site NIT-55 with collapse vectors indicating direction of fall.

An image of the home can be viewed clicking the thumbnail (Figure 7). Google earth is used here to correlate directional patterns of damage with the strong motion data recorded at several sites in the city. This is important if many of the collapses can be associated with one or several specific pulses of motion that exceeded the capacity of the structures to resist failure. Then, the amplitude and frequency characteristics of these pulses can be analyzed, and specific design recommendations can be established to construct new structures, or retrofit surviving structures, to adequately resist these motions.

There have also been gains in safety: the 'big picture' coordination that the software facilitates allows the actual site visits to be reduced, with fewer researchers needing to travel to a disaster site. By merging spatial aspects with the damage patterns (e.g. distance from the earthquake source), researchers can better assess the performance of structures and ground in a load-capacity framework. This means that with location data, better control on the source distance, and more visual, observational data in one place (a Google Earth kml file), researchers can better characterize the engineering performance of features in the study area.

GOOGLE EARTH AS A LEARNING TOOL

In the reconnaissance of the Niigata earthquake of 16 July 2007, we used Google Earth in the field for collection and organization of damage data and to guide the reconnaissance activities. In that sense it was used as a free, field-capable geographic information system (GIS) application by practitioners. After the investigation, the Google Earth .kml file became a major component of the formal report products on the earthquake. Many aspects of this earthquake investigation are paralleled by other studies undertaken by the London Knowledge Lab utilizing mobile tools in scientific fieldwork. Specifically the lab monitors students studying earth and life sciences in the field, links them with experts in real time, and engages them in the practices of expert scientists [Smith and Walker, 2007; Walker, 2007]. These studies also include the use of Google Earth and parallel in methodology, the manner of the earthquake reconnaissance study described here.

In the London Knowledge Lab studies, students use camera phones with built-in or external (Bluetooth) GPS capabilities to take geo-referenced photos that are automatically uploaded to a server with GPS location coordinates. In the earthquake study described here, we used camera phones in some cases to take photos and as GPS devices. The use of GPS camera phones was limited because (1) we use higher-resolution digital cameras, and (2) we use more precise GPS hardware. However, there is a distinct need for more immediate uploading of the data from the field that phones provide. In the future, as higher resolution camera phones with GPS functionality become available, these will be used to send data directly to a server from the field, saving time in collecting and processing them in batches in the evenings, and giving other investigators not exposed to hazards and fatigue in the field, an opportunity to organize the data.

Figure 7. Photograph of house collapse at site NIT-55 that is linked to the thumbnail image in the balloon in Figure 6

The students in the London study upload geo-tagged photos to Flickr, a photo-sharing web site, from which Google maps can be automatically generated using a feature referred to as 'mash ups' that benefit from the open source nature of both software products [Ames and Naaman, 2007; Ludford, et al. 2007]. The use of Flickr and Google mapping products holds promise as combined tools in future post-disaster investigations, especially if the Flickr capability is linked to Google Earth.

The reconnaissance in Niigata, Japan, was driven by scientists and engineers in a traditional manner with experts developing methods that may then be used to instruct students. On the other hand, the London trials in effect act as a testing ground for software and practices for the scientists; in that case, experts were learning from students, a rare instance.

A large part of becoming part of a scientific community is learning the language and specialized terminology that experts use. In this case, the visual nature of Google Earth enables students who view the product to see visual examples of damage aspects in the form of maps, photos, and linked data that allow for better understanding of technical terms.

In the case described here, the Google Earth map of the reconnaissance was developed in English. The visual nature of the software allows speakers of many languages to share in viewing and interpreting the data. The software also has the ability to translate text into other languages at the click of a button. This universal language functionality is a tool we would like to further explore. For international investigations, it will be particularly useful for colleagues to express themselves in the language they are most adept at, and allow for translation software to assist in conveying the meaning in other languages.

CONCLUSIONS

The use of Google Earth significantly advanced the capabilities of our recent post-disaster investigation, as compared with previous mapping software typically used by disaster reconnaissance team members. The easy data merging and sharing capabilities of Google Earth translated into a more thorough scientific investigation in addition to significant cost reductions of the field effort by (1) more efficiently guiding the reconnaissance in the field; (2) identifying redundant data sets gathered by different teams; (3) allowing researchers outside of the investigation area to see the data and imagery in a spatial context so that they could virtually participate in the study; and (4) expanding the free data set available to researchers in paperless format who download a .kml with links to larger data sets (imagery, animations, data tables) on servers. Additionally, there were likely some gains in safety. By creating a format that allows researchers to virtually visit the damage area, fewer investigators are exposed to disaster area hazards (e.g. strong aftershocks, further collapse of structures, post-disaster related-diseases associated with decay, and loss of clean water and sanitation services). Google Earth will also enable links between experts and students within a scientific community of practice, in which students can participate in and learn expert practices, and experts learn from technical experiments carried out by students.

To view the Google Earth map file of the earthquake investigation discussed in this paper, go to.

http://walrus.wr.usgs.gov/infobank/n/nii07jp/html/n-ii-07-jp.sites.kmz

A companion investigation report on the earthquake can be found at and

http://pubs.usgs.gov/of/2007/1365/

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