Landslide Risk Assessment with High Spatial Resolution Remote Sensing Satellite Data

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ABSTRACT

Landslide identification and mapping are essential for landslide risk and hazard assessment. This paper reports on the uses of remote sensing techniques for mapping landslide areas ranging in size from large to small. High-resolution stereo SAR and optical images are providing useful information for detailed mapping of large landslides, however mapping of smaller scale slides still requires extensive use of airphotos and fieldwork.

INTRODUCTION

Landslides are mass movements of soil or rock down slope and are a major natural hazard, because they are widespread. Globally, landslides cause approximately 1000 deaths a year with property damage of about US $4 billion (ISU, 1993). Landslides pose serious threats to settlements, structures that support transportation, natural resources management and tourism. They do considerable damage to lifelines and especially to highways, railways, waterways and pipelines. They commonly occur with other major natural disasters such as earthquakes and floods caused by heavy rainfall. Damage from landslides and other ground failures have sometimes exceeded damage directly related to earthquakes. In many cases, expanded development and unwise human activity, such as modified slopes and deforestation, can sometimes increase the incidence of landslide disasters. The pressure for continuing development in urban areas many times leads to expansion upon unstable terrain. This has thrown many urban communities into disarray, providing grim examples of the extreme disruption caused by ground failures.

Minor landslides, more appropriately referred to as small-scale slope failures, do not cause the catastrophic damage of large-scale landslides. Small slides frequently occur in compacted embankments constructed for highways, levees, and small earth dams and can also occur in shallow cut slopes. They occur both in hilly or mountainous terrain and in areas with rolling or flat topography. While small slides generally pose little direct threat to human well being, maintenance and repair of these slides constitutes a tremendous economic burden due to the extremely high number of small slides encountered. Because of the non-threatening appearance of minor slope failures very little data is available to define how extensive the problem is and the impact they have on our lives. However, the U.S. Transportation Research Board (1996) recently reported that annual maintenance costs incurred for repair of minor slope failures by state departments of transportation that have kept “good maintenance records” was more than $100 million! This amount equaled or exceeded the costs for repair of major slope failures by these agencies.

LARGE-SCALE LANDSLIDES

Methodology

Aerial photography has been used extensively to characterize landslides and to produce landslide inventory maps, particularly because of their stereo viewing capability and high spatial resolution. Airphotos were used to identify steep slopes underlain by weak soils, slopes undercut by rivers and waves, tension cracks, steep hummocky topography, failed surface scarps, anomalous bulges and lumps, terraced slopes, discontinuous bedding planes, drainage vegetation patterns and elongated ponds on hillslopes (Alfoldi, 1973;Mollard, 1977; Nilsen and Brabb, 1977; Cruden and Lu, 1992; Savigny, 1993;).

Current research has shown that high-resolution stereo SAR and optical images, combined with topographic and geological information have assisted in the production of landslide inventory maps. The multi-incidence, stereo and high resolution capabilities of RADARSAT are particularly useful for landslide inventory maps. High-resolution optical systems such as IKONOS and IRS and the stereo capability of SPOT 4, are useful for landslide mapping and related land use mapping. The spatial resolution of satellite data TM and SPOT are generally too coarse for landslide characterization, and are used in combination with detailed air photos. This synergistic use of satellite images for landslide hazard assessment is demonstrated by Singhroy, 1995; Leroi et al.,1992; McKean et.al 1991; Rengers et al.,1992; Koopmans and Forero, 1993. Other planned high-resolution stereo SAR systems such as ENVISAT, RADARSAT 2 and ALOS will be useful for mapping landslide features.

CASE STUDY OF LARGE LANDSLIDE

The Fraser valley, in the Canadian Cordillera, is one of the most strategically important transportation corridors in Canada. Almost all the transportation lifelines that link the resource rich prairie provinces with metropolitan Vancouver utilize this corridor. Recently, landslides caused serious damage to the major transportation links. In the spring of 1997, landslides have caused the derailment of the CN railway resulting in two deaths and 20 million dollars of damage. In 1965, a large rock avalanche (48 x 10 6 m 3) known as the Hope slide, occurred 160 km east of Vancouver. The slide, probably triggered by two small earthquakes (M 3.2 and 3.1), buried three vehicles and claimed four lives. Thirty-five large landslides ranging in size from at least 1 million to more than 500 million cubic metres have been identified in the Fraser Valley. The causes of landslides in the area include the weakening of failure planes in carbonate rocks, solution erosion, seismic shaking, the presence of clay infilling along discontinuities, steep slopes, excessive precipitation and deforestation. These slides mainly occur along the contact between plutons and metamorphic pendants and are associated with regional north trending thrust and strike slip faults. CCRS airborne interferometric SAR, and high-resolution (8m) RADARSAT images were used to map the geomorphic features of the landslide areas (Singhroy *et al.*,1998). The airborne InSAR image technique provides an accurate representation of the slope geomorphology. This facilitated the identification of landslide features in these difficult high relief terrains. Major geomorphic features such as (1) block slide, (2) debris slide, (3) slide scarp, (4) transverse ridges, and (5) faults associated with the landslides are well expressed and easily interpreted on the InSAR images. The fine mode RADARSAT (8m) images is the highest spatial resolution satellite SAR available to date, and is suitable to identify some landslide features for a regional scale mapping. The fine mode RADARSAT images also have the most suitable incidence geometry (40-60 degrees) because of less distortion in these high relief terrains (Singhroy and St.Jean, 1999). In most cases, 5m stereo SAR images are recommended for more detailed landslide characterization (Singhroy, 99).

SMALL-SCALE LANDSLIDES

Utilization of remote sensing data and high resolution satellite images for identification of small-scale slope failures poses unique challenges in addition to those encountered for identification of large landslides. Characteristic dimensions of small slides generally range from 10 to 100 meters. Depths of sliding are also relatively low ranging from 1 to 3 meters. Features thus lie at the boundary of currently available satellite image resolutions. However, there are aspects of the small landslide problem that justify the application of remote sensing technology to assist on the detection and monitoring of these features. In contrast to large landslide applications that are focused on the identification, hazard assessment, and planning for emergency measures, the focus of small scale slide problems lies in creating an inventory of areas where slides have already occurred. Therefore, for this application the failure to identify a given slide is not critical whereas the misidentification of a large-scale slide may have dramatic and potentially tragic consequences. Small landslides are also generally concentrated in restricted areas such as transportation routes, levee systems, and dam sites. The areas to be evaluated are, therefore, of limited size leading to higher probability of slide detection. Furthermore, higher priority may be placed on monitoring restricted areas with known problems or prone to recurrent slope

failure thus leading to the use of unique feature detection algorithms.

Currently available remote sensing tools do not eliminate the need for ground-based observation and mapping of small slides. However, remote sensing images can be used to economically assist with small slide management and provide information to facilitate ground based investigations.

Preliminary investigations have been performed to evaluate and develop methods for identifying objects with similar scale using remote sensing techniques (Karimi *et al*., 2000). Results of this and similar research is expected to provide significant benefits to use of remote sensing for small scale landslide management. Identification and tracking of small scale slides could also be greatly facilitated by use of spectral imaging. However, the combination of high spatial and spectral resolution remote sensing data required for this use is not currently available.

CONCLUSIONS

- Results of application projects show that high-resolution stereo SAR and optical images (<10m) are being used to characterize landslide areas.
- The potential of InSAR data to produce detailed slope maps can assist in more accurate slope stability studies.
- The technology to use of satellite remote sensing data for identification and mapping of small-scale slope failures is not in available yet. However, there is a potential value for the application of multispectral and pan data at least 1m spatial resolution.

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