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GERALD F. WIECZOREK (*)

DIRECTIONS OF THE U.S. GEOLOGICAL SURVEY LANDSLIDE HAZARDS REDUCTION PROGRAM

Abstract: WIECZOREK G.F., *Directions of the U.S. Geological Survey Landslide Hazards Reduction Program* (IT ISSN 0391-9838, 1993).

The U.S. Geological Survey (USGS) Landslide Hazards Reduction Program includes studies of landslide process and prediction, landslide susceptibility and risk mapping, landslide recurrence and slope evolution, and research application and technology transfer.

Studies of landslide processes have been recently conducted in Virginia, Utah, California, Alaska, and Hawaii. Landslide susceptibility maps provide a very important tool for landslide hazard reduction. The effects of engineering-geologic characteristics of rocks, seismic activity, short and long-term climatic change on landslide recurrence are under study. Detailed measurement of movement and deformation has begun on some active landslides.

The U.S. Geological Survey is working to transfer available information on landslides to people and entities concerned with landslide hazard analysis and mitigation, in order to effect improved land-use planning, engineering design and construction, warning and emergency response. For this purpose, the U.S. Geological Survey has developed the National Landslide Information Center in Denver, Colorado.

KEY WORDS: Landslide hazard, Risk mapping, Land use management.

Riassunto: WIECZOREK G.F., *Indirizzi del Programma di Riduzione dei Rischi da Frana dell'U.S. Geological Survey* (IT ISSN 0391-9838, 1993).

Il Programma di Riduzione dei Rischi da Frana (*Landslide Hazards Reduction Program*) dell'U.S. Geological Survey comprende gli studi sui processi franosi e la loro predizione, la suscettibilità a franare e la cartografazione del rischio, la ricorrenza delle frane e l'evoluzione dei versanti, il trasferimento di tecnologie.

Studi sui fenomeni franosi sono stati recentemente condotti in Virginia, Utah, California, Alaska, Hawaii. Le carte della suscettibilità a franare forniscono un importante strumento per la riduzione del pericolo di frane. Sono in corso di studio gli effetti delle caratteristiche geologico-ingegneristiche delle rocce, l'attività sismica, il cambiamento a breve e lungo termine del clima. Sono inoltre iniziate misure di dettaglio del movimento e della formazione di frane attive.

L'U.S. Geological Survey sta lavorando per trasferire le informazioni disponibili sulle frane alla popolazione e agli enti che si occupano dell'analisi e della riduzione del rischio da frana, al fine di rendere efficace la pianificazione territoriale, la progettazione e l'esecuzione di opere, la reazione di allerta e di emergenza. A tale scopo, l'U.S. Geological Survey ha sviluppato a Denver, in Colorado, il *National Landslide Information Center*.

TERMINI CHIAVE: Pericolosità da frana, Cartografazione del rischio, Pianificazione territoriale.

INTRODUCTION

In the United States, studies of landslides are conducted by scientists and engineers of government agencies, universities, and private consulting companies. In 1980 the United States Congress authorized the U.S. Geological Survey (USGS) Landslide Hazards Reduction Program; in fiscal year 1990, the program was funded at a level of approximately $2.2 million. The USGS's Landslide Hazards Reduction Program is a focal point of landslide research in the United States Government. Landslide research within the USGS in conducted by a professional staff of 15 geologists and engineers from offices in Reston, Virginia; Denver, Colorado; and Menlo Park, California. Scientists with State governments have been contracted or have entered into cooperative arrangements with the USGS to carry out additional landslide investigations. The main components of the program include studies of landslide process and prediction, landslide susceptibility and risk mapping, landslide recurrence and slope evolution, and research applications and technology transfer.

This paper describes the highlights of recent accomplishments, descriptions of work underway, and directions of future research. Locations of landslide studies described in this paper are shown in Figure 1.

(*) *U.S. Geological Survey, Reston, VA 22092, U.S.A.*
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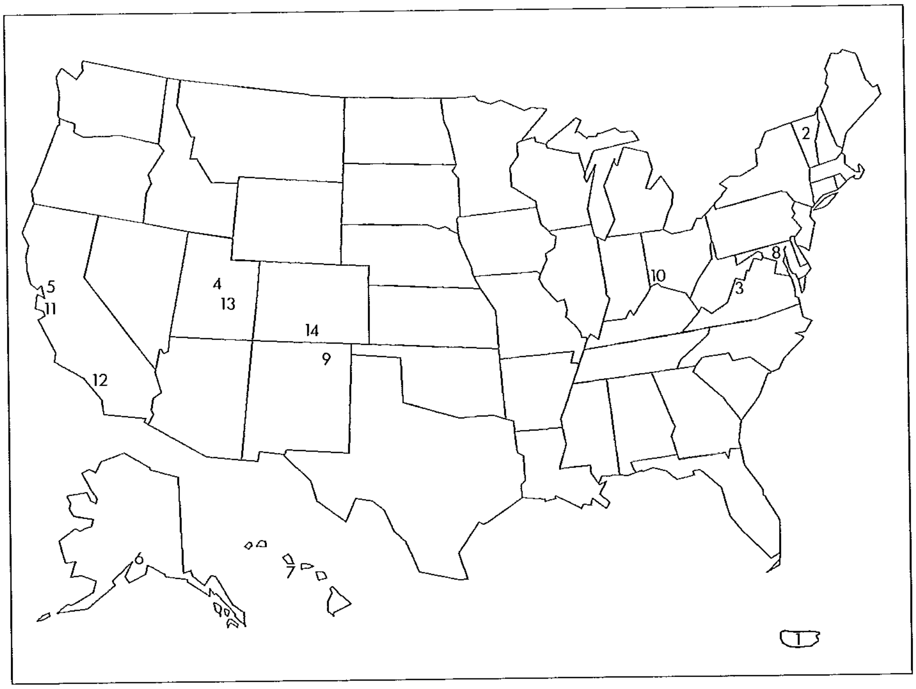

FIG. 1 - Locations of landslide studies referred to within text. Alaska, Hawaii and Puerto Rico are not shown in proper geographic location. In order of discussion in text: 1) Puerto Rico, 2) Windsor, Vermont, 3) Central Appalachian mountains of Virginia/West Virginia, 4) Wasatch Front and Plateau of Utah, 5) San Francisco Bay region, California, 6) Anchorage, Alaska, 7) Honolulu, Hawaii, 8) Maryland, 9) New Mexico, 10) Cincinnati, Ohio, 11) San Mateo, California, 12) Los Angeles, California, 13) Manti, Utah, and 14) Lake City, Colorado.

PROCESS AND PREDICTION

In October of 1985 tropical storm Juan struck southern Puerto Rico and triggered hundreds of landslides (JIBSON, 1989). Data on bedrock lithology and structure; properties of colluvium and residuum; slope aspect, steepness and profile; and rainfall during the storm are being digitized for use as independent variables in a multivariate modeling procedure to determine factors significantly correlated with landslide susceptibility.

During 1984 in Windsor Country of central Vermont, heavy seasonal rainfall and melting of a thick snowpack triggered earth flows, slumps, and earth-block slides in Pleistocene surficial materials. BASKERVILLE & OHLMACHER (1988) documented these landslides and studied the relation between the slope failures and properties of the geologic materials. Investigation of rock falls and rock block slides in the northern Appalachian Mountains of Vermont was undertaken to better understand the processes and the conditions leading to failure (BASKERVILLE & *alii*, 1988). Site specific monitoring studies were initiated to quantify and correlate climatic events and slope deformation rates in foliated and jointed metamorphic rocks (LEE, 1989).

In November of 1985, a storm in the central Appalachian Mountains of Virginia and West Virginia triggered more than a 1000 shallow landslides in thin colluvium and residuum on shale slopes within a 1040 square kilometer study area (JACOBSON & *alii*, 1989a). Climatic conditions and the relative importance of land cover, bedrock and surficial geology, and geomorphology to location of landslide initiation were examined. Rainfall thresholds for the triggering of landslides were identified for individual geologic units (JACOBSON & *alii*, 1989a).

In the western United States recent studies of landslide processes have been conducted in Utah, California, Alaska and Hawaii. In both 1983 and 1984, heavy autumn rains, exceptionally thick winter snow packs, and sudden warming triggered abundant landslides along the Wasatch Front and on the Wasatch Plateau of Utah. The climatic, hydrologic, geologic and topographic conditions where landslides initiated were closely examined for better understanding of landslide processes and for improving landslide hazard zonation techniques (BAUM & FLEMING, 1989; WIECZOREK & *alii*, 1989).

Regional and topical studies of landslide processes in the San Francisco Bay region of California over several decades provided a background for developing landslide prediction techniques. Following detailed documentation of landslide location, timing and rainfall in the January 1982 storm (ELLEN & WIECZOREK, 1988), a regional landslide warning system was developed and first utilized to issue a warning during storms of February 1986. This system was based on empirical and analytical relations between rainfall and landslide generation, monitoring of regional rainfall data from telemetry rain gages, United States National Weather Service precipitation forecasts, and delineation of areas susceptible to landslide generation (KEEFER & *alii*, 1987).

To provide better calibration for rainfall-induced landslide triggering relations, an analytical model was developed, based on measured piezometric response to depict the influence of intense rainfall on pore pressures within a hillslope (WILSON, 1989); other improvements in the landslide warning system have also been undertaken (WIECZOREK & *alii*, 1990). Detailed monitoring of porewater pressures from instrumented slopes in Utah and California detected an abrupt drop in pore pressure immediately before failure of the slopes. This observation has potential application in future landslide hazard warning systems (HARP & *alii*, 1990).

A cooperative project between the USGS and the State of Alaska Division of Geological and Geophysical Surveys undertook investigations of the landslides which occurred during the March 27, 1964, Prince William Sound, Alaska earthquake. Geotechnical studies in and around Anchorage, Alaska, identified a sensitive silty clay facies of the Bootlegger Cove Formation which, when subjected to seismic shear stresses, exhibited rapid strength reduction and was responsible for all the major Anchorage landslides during the 1964 earthquake which had previously been attributed to liquefaction of sandy facies (UPDIKE & CARPENTER, 1986; UPDIKE & *alii*, 1988 a,b).

In Honolulu, Hawaii, a study of the mechanics of slow-moving landslides using surface and subsurface testing, instrumentation and monitoring is being conducted to develop new methods of hazard mitigation (BAUM & *alii*, 1989; BAUM & FLEMING, *in press*). Maps of debris-flow hazards are being prepared for parts of Honolulu based on field mapping of deposits and utilizing computer runout models. Field instrumentation of rainfall and shallow ground-water levels at several sites, combined with hydrologic analyses, are being used to develop rainfall thresholds for a landslide warning system similar to the San Francisco Bay region, California.

LANDSLIDE SUSCEPTIBILITY AND RISK MAPPING

Accurate maps of regional and State landslide hazards are a prerequisite to successful landslide hazards reduction. Information on the location and magnitude of landslide activity, and the susceptibility to future landslide movement, must be available to effect improved land-use planning, engineering design and construction, and warning and emergency response. Beginning informally in 1982, and augmented from 1985 through 1987 by a cooperative Federal-State landslide program, the USGS encouraged State geological surveys to prepare landslide inventory maps (e.g. RHEAMS & *alii*, 1987), to formulate state landslide hazard mitigation plans (e.g. JOCHIM & *alii*, 1988), and to undertake special investigations of specific landslides or geologic units prone to landsliding (e.g. AMOS & SANDFORD, 1987).

As a prototype, a State landslide susceptibility map of Maryland was prepared with categories of susceptibility that were based on professional engineering geologic judgement and field experience of slope stability in individual mapped geologic units (POMEROY, 1988). In order to develop and test new techniques for preparing State susceptibility maps, BRABB & *alii* (1989) prepared a regional landslide inventory map for northern New Mexico. Geographic Information Systems (GIS) technology is being employed with digitized data on 127 geologic units along with slope and landslide inventory data to develop models for evaluating the probability of landsliding and to assist in the systematized preparation of landslide susceptibility maps for New Mexico.

In a study of landslide hazards in Cincinnati, Ohio, BERNKNOPF & *alii* (1988) demonstrated that the economic costs and benefits of different mitigation strategies could be used as the basis for land use decisions. To evaluate the spatial distribution of expected landslide losses in the Cincinnati study area, regional geologic and topographic information was used to establish a regression equation that estimated the probability of landslide occurrence in 100-m square units. The probabilistic assessment of landslide susceptibility provides an essential tool for economic evaluation of community-imposed requirements for landslide hazard mitigation.

Several methods have recently been developed for assessing seismically-induced landsliding on a regional scale. A seismic slope stability map of San Mateo County in northern California, was developed from an analysis of potential landslide displacement during different characteristic earthquakes as a function of regional bedrock geology, slope, and ground-water levels (WIECZOREK & *alii*, 1985). In the Los Angeles region of southern California, the areal limits of landsliding from a postulated earthquake were assessed using a different technique incorporating theoretical and historical-empirical studies of distances from earthquake sources at which different landslide types occurred (WILSON & KEEFER, 1985; KEEFER & WILSON, 1989). In this method, the distance limit of earthquake-induced landslides from 40 historical earthquakes worldwide was used to determine an outer bound limit of distance as a function of earthquake magnitude. The Arias intensity, a measure of the severity of seismic shaking, was used to develop probability estimates for exceeding an Arias intensity threshold for triggering landslides at a particular distance from an earthquake source. In other ongoing work, HARP (this volume) is using strong-motion records and landslide distribution from several recent earthquakes to refine the use of Arias intensity thresholds for landsliding.

LANDSLIDE RECURRENCE AND SLOPE EVOLUTION

In early 1974, the upper part of the Manti landslide near Manti, Utah began moving and a little more than a year later, movement extended the full 3 km length of the old dormant landslide. Investigations into the history of the reactivation were undertaken including determining the rates of landslide enlargement and displacement (FLEMING & *alii*, 1988a); the physical properties and mode of failure of the landslide (FLEMING & *alii*, 1988b); and the hydrologic changes associated with the landslide movement (WILLIAMS, 1988).

Additional investigations of the Manti landslide are underway using a variety of Quaternary dating techniques to study the influence of short-term climatic change on slope failure. The influence of short- and long-term climatic changes on rates, processes, and geographic distribution of landslide activity will be examined elsewhere to better understand climatic influence on landslide recurrence.

Detailed measurement of movement and deformation has begun on the actively moving Slumgullion landslide near Lake City, Colorado. One of the purposes of the work is to improve quantitative methods of evaluation of hillslope stability and to predict enlargement and changes in rates of movement of landslides. Field and aerial photographic measurements of precise size, shape, and position of various movement features indicate, in addition to changes in rate and size, the potential options for stabilization (BAUM & *alii*, 1989). Additional investigations of the Slumgullion landslide will also provide new information on the response of large landslides to climate change. The Slumgullion landslide, like many other large landslides worldwide (SCHUSTER, 1986), formed a prehistoric landslide dam that could provide information in the sedimentologic record for determining the climatic influence on landslide movement.

Studies of the surficial stratigraphic record of the central Appalachians in the eastern United States by JACOBSON & *alii* (1989b) have revealed a profound climatic influence on slope processes. Most of the region exhibits multiple, prominent hillslope and alluvial terrace deposits indicative of climate changes with durations and recurrence frequencies of tens of thousands of years or more. Holocene catastrophic events have only caused minimal erosion of these features that appear to be associated with a very different climate in the Pleistocene (JACOBSON & *alii*, 1989b).

RESEARCH APPLICATIONS AND TECHNOLOGY TRANSFER

The USGS is working to provide private individuals, commercial and industrial establishments, and local, State and Federal government institutions with the information to evaluate systematically the level of landslide hazard to which they are exposed. The USGS transfers landslide susceptibility maps and risk assessments, regional and local landslide prediction procedures and methodologies, and results of landslide research. As a direct form of research application and technology transfer, the USGS provided assistance to Federal, State, county, and local agencies during recent landslide disasters in the San Francisco Bay region (1982, 1986 and 1989); in Utah (1983, 1984); in Puerto Rico (1985); in Virginia, West Virginia (1985); and in Hawaii (1988). The assistance in these cases has ranged from short-term, post-disaster reconnaissance studies with immediate mitigation recommendations to several-year long projects involving intensive investigations and development of comprehensive mitigation plans. For example, a 1- to 2-year, program of studies of landslides caused by the October 17, 1989, Loma Prieta earthquake, was funded by the Federal Emergency Management Agency, and cooperatively directed by the USGS, U.S. Corps of Engineers, State of California-Division of Mines and Geology, County of Santa Cruz, and University of California at Santa Cruz. The results of these studies will influence land-use regulations on landslide-prone terrain in Santa Cruz County, California.

To improve technology transfer, the USGS is developing a National Landslide Information Center (NLIC) in Denver, Colorado. The NLIC will be a multi-functional enterprise dedicated to the collection and distribution of all forms of information related to landslides-data from landslide monitoring projects, digital data files of landslide inventories, and geographical information system (GIS) digital representation of landslide susceptibility and risk, as well as traditional published maps, reports, and books. Over the next decade the NLIC will be developed to serve landslide researchers, geotechnical practitioners engaged in landslide stabilization, and all other people and entities concerned in any way with landslide hazard analysis and mitigation.

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