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Earthquake-induced landslides from horseback surveys through GIS analyses (Sergey Soloviev Medal Lecture)

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Landslides are among the most widespread of earthquake effects. In great earthquakes, landslides can number in the tens of thousands and occur hundreds of kilometers from the causative fault rupture. They can cause significant changes in the landscape and, by such processes as damming rivers, can present hazards to life and property that persist long after the earthquake shaking has stopped. They have killed thousands of people in recent earthquakes, and they are among the leading causes of earthquake-related economic losses. Thus understanding and forecasting their occurrence is important in both scientific and practical terms.

The empirical association between earthquakes and landslides has been noted for thousands of years, and the study of earthquake-induced landslides has progressed from anecdotal accounts, through horseback surveys, to mapping from aerial photography, and most recently to analysis using Geographic Information Systems (GIS). Likewise, analytical studies of slope stability during earthquakes have progressed from pseudo-static models, where earthquake shaking is treated as a constant additional force, to a variety of dynamic models that account for both the transient characteristics of input ground-motion and the variety of potential slope-failure mechanisms.

These developments have both shown and responded to the complex nature of landslides triggered by earthquakes. Such landslides can be classified in a number of ways, but one widely used classification system separates them into 3 main categories and 14 different individual types. Each type of landslide occurs in particular geologic environments and involves particular failure mechanisms, such as tensile cracking, shear failure, or liquefaction. These landslides also vary greatly in their size, velocity, and distance of travel; the largest and most mobile involve tens of millions of cubic maters of material, and travel distances of several kilometers at velocities that can exceed 100 km/hr. Accurately characterizing earthquake-induced landslides thus involves documenting many parameters during immediate post-earthquake investigations and then developing analyses to treat a wide variety of mechanisms and conditions.

The generation of research up to the present has greatly increased our understanding of earthquake-induced landslides. On a regional scale we now have developed general relations between the magnitude of the triggering earthquake and several measures of landslide abundance and distribution, including numbers of landslides, areas affected by landslide occurrence, and maximum distances of landslides from the earthquake epicenters and fault ruptures. We have similar general relations between landslide occurrence and seismic intensities. We also have several empirical and analytical methods to forecast where landslides are most likely to occur in future earthquake scenarios. On the scale of individual landslides, we know much about the types of landslides specifically triggered by earthquakes and the types of slopes that produce each. We have analytical models of the main failure mechanisms, and can carry out analyses to determine whether particular slopes are likely to fail given specified future earthquake shaking.

However, we still have much to learn. New remote sensing capabilities enable us to map the landslides triggered by an earthquake more completely, and GIS analyses enable us to develop much more detailed and specific relations between seismic and geologic parameters, on the one hand, and landslide occurrence on the other. Additional development and application in these areas, along with the continuing development of analytical techniques to characterize initiation and, especially, movement of landslides can be expected in the next generation of research. Such research should lead to a more detailed and specific understanding of where earthquake-induced landslides will occur and what their characteristics will be. Ultimately, this research should also lead to lessening the loss of life and economic damage associated with future earthquakes.