Paleoseismic and geologic data for earthquake simulation

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Abstract

Paleoseismic and geologic data are essential for assimilation into physically based numerical simulation models. Such data are fundamental to understanding the spatial and temporal scales of complete earthquake cycles. Geologic data are necessary for identifying the locations and characteristics of active faults. Paleoseismic observations yield observational data on the temporal and spatial rupture characteristics of moderate to large earthquakes over multiple earthquake cycles. The value of compiling paleoseismic and geologic data for use in seismic hazard analysis has been realized for a number of decades. Many challenges arise, however, when designing such a database. These difficulties include scale and unit standardization, multiple measurements at a single site, diverse or discrepant data for a given fault, and fault data presented as a range.

Significance of paleoseismic and geologic data

A primary objective of the ACES science plan is *"...to develop physically based numerical simulation models for the complete earthquake generation process and to assimilate observations into these models...at all time and space scales relevant to the earthquake cycle*" [1]. Development of simulation models that can forecast the occurrence of large events would be the most important contribution of the ACES program. There are abundant records of seismicity and geodetic observations at a range of spatial scales extending back several decades, but these data sets do not span the complete earthquake cycle and therefore are insufficient for achieving the goals of ACES. Paleoseismic and geologic data must be assimilated into the models to understand the earthquake generation process over the full seismic cycle, particularly for large magnitude events that release most of the seismic moment and represent the greatest threat to society.

Data types and assimilation challenges

Geologic data provides the material framework for earthquake simulation models by defining the locations and characteristics of faults. Paleoseismology is the study of earthquakes that occurred prior to instrumental monitoring. Paleoseismic observations provide data on spatial and temporal rupture patterns of large earthquakes over multiple seismic cycles, and long-term rates of strain release (slip rates). Assimilation of geologic and paleoseismic data presents different challenges than incorporation of large seismicity and geodetic data sets. Geologic and paleoseismic data sets are small, sparse, partly analog, and include large uncertainties.

The value of compiling geological and paleoseismic data for seismic hazard assessment has long been recognized. In the U.S., several databases exist or are being developed. Most existing data sets also include interpretation co-mingled with direct observation so that the data sets are not suitable for hypothesis testing or predictive simulation. For example, U.S. National Seismic Hazard Maps are based on a database that includes interpretive parameters such as fault segments. We are developing a database for a transcurrent tectonic regime (California) that will meet the scientific objectives of ACES/GEM (see Table). Separation of objective and subjective data will allow assimilation of data into models with minimal bias.

Fault location and geometry	2-D, or 3-D at locations where known.
Kinematic indicators (sense of motion)	At location of observation, with uncertainty
Slip rate and time interval	At location of measurement, with uncertainty
Rupture history at locations of observation	Dates of individual ruptures where known or number of ruptures within a time interval, measurement of surface displacement, uncertainty dates and number of ruptures
Subjective or interpretive parameters	Examples: fault segments, faults that are proposed to exist but have not been directly observed, and models of fault geometry.

Table: Components of a geologic and paleoseismic database for earthquake simulations

Many challenges arise when considering the structure and content of such a database. To accommodate the numerical needs of the largest number of scientists, it is desirable to include data at an appropriate scale and in preferred units. Scales and units suitable for simulations commonly differ from raw data formats. Other challenges include handling the inclusion of multiple measurements from a given location on a fault, including how to reference all applicable scientists and studies. In California, many researchers have focused on a few faults, such as the San Andreas. This can lead to a relatively large volume of diverse and possibly conflicting geologic data for a specific fault, and few or no observations for other faults. An additional difficulty arises when available fault or rupture data are given as a range. Generally, computer models require a single number parameter, such as fault length or end point location. Providing data as a range could inconvenience the modelers although it may be necessary to accurately represent uncertainty in the data.

Example

The Carrizo segment of the San Andreas fault in California exemplifies the challenges associated with the assimilation of paleoseismic and geologic data into simulation models. Several scientists have conducted fault studies near Wallace Creek along the Carrizo segment of the San Andreas fault. Paleoseismic and geologic data collected less than 10 km apart are dissimilar. For example, the published recurrence intervals for study sites near Wallace Creek are 150 to 300 years [2], 160 years [3], and 240 to 450 years [4]. The disparity between these recurrence intervals is important for modeling fault behavior, and, in order to reduce bias, all of these data should be included in fault databases so they will be available for assimilation into models.

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