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Comprehensive modeling of earthquake-induced landslides for regional disaster mitigation

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We have developed a comprehensive areal model of earthquake-induced landslides (CAMEL). CAMEL improves upon the state of the art by predicting the possibility and hazard (as landslide concentration) for all major types of landslides caused by earthquakes (treated as six types within the model framework) with the exception of lateral spreads. CAMEL was designed specifically for use with the U.S. Geological Survey's ShakeMap product for scenario prediction and near real-time interpolation of ground shaking intensity based on instrumental measurements. CAMEL affords great flexibility in characterizing input conditions; for example, shear strength data for rock and soil are not required for characterizing slope material conditions. This flexibility is gained largely through the use of the modeling methodology of computing with words (CW). CAMEL was developed as a fuzzy logic system, the foundation of CW, to facilitate quantitative and qualitative representation of input conditions, inferential knowledge about these inputs, and associated uncertainty. This is accomplished by mapping numbers to words to be able to express algorithmic knowledge elicited from experts and the scientific literature as a set of linguistic IF-THEN rules. To ensure the quality of the knowledge embedded in CAMEL, in addition to the model's predictions, empirical evaluation of CAMEL was conducted. We compared outputs from CAMEL with the landslide inventory from the 1989 M = 6.9 Loma Prieta, California (USA) earthquake to see that landslide concentration predictions were generally on target. The results of the empirical comparison were judged against a similar evaluation of a popular existing model based on Newmark's displacement method. Comparison showed that landslide concentrations predicted by CAMEL are generally consistent with the Loma Prieta landslide inventory, at least for the most common types of landslides. CAMEL appears to perform best with respect to disrupted

soil slides, falls, and avalanches, whereas it over-predicts the areal concentrations of rock avalanches, rock slides and rock falls. CAMEL compared very well with the state of the practice of earthquake-induced landslide modeling, represented by the simplified Newmark-based model employed. CAMEL, however, does not represent an alternative or replacement to Newmark-based models. Because it is a knowledge-based model, CAMEL can incorporate predicted Newmark displacements as input from which to infer landslide concentrations for one or more landslide types.