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Deposition in a Hazard Assessment Model of Mass Transport Complexes

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Abstract

A probabilistic model is proposed to describe the probability distributions of MTC hazards. Existing deposits appear to validate the model to the degree possible. The model reproduces deposit structures, and also identifies model inputs that are most likely to produce hazardous MTCs.

Introduction

A mass transport complex (MTC) can present significant hazards to certain offshore structures and activities. Specifically, the integrity and operations of underwater cables, pipelines, moorings, and other structures can be threatened by MTCs. An effective and manageable use of these structures motivates a study of MTC hazards. In general, MTC hazards are revealed by field studies of existing MTC events (Orange et al., 1999; Tappin et al., 2001, 2003; von Huene et al., 2004). Field studies are complimented by numerical models developed to evaluate MTC hazards. These include various sediment stability models (e.g., Wright and Rathje, 2003), mass transport models (e.g., Imran et al., 2001; Syvitski and Hutton, 2003; Niedoroda et al., 2003), and probabilistic models (e.g., Watts, 2003, 2004). Of these different techniques, probabilistic models have perhaps received the least attention, despite their many advantages. In this work, MTC hazards are found by combining 1) stability analyses and 2) sediment motion into a single hazards assessment model (HAM). The HAM is a probabilistic model that provides probability distributions for most MTC hazards of interest.

Hazard Assessment Model

The HAM presented here is based in part on the probabilistic model of Watts (2003), although the HAM is significantly more sophisticated. HAM inputs include slope morphology, sediment strength, sedimentation rate, water pressures, gas hydrate pressure and temperature, seismic parameters and other slope stability factors. The stability of any given slope may be dominated by only a few model inputs (Watts, 2004). The frequency of MTCs is controlled by the rate of occurrence of storm waves, earthquakes, gas hydrate phase change, oversteepening, sedimentation events and other MTC triggering mechanisms. The HAM performs two distinct computations. Stability analyses of sediment structures evaluate MTC failure planes. Sediment motion post failure describes MTC velocities and deposition.

There are several important differences between our earlier work (Watts, 2003, 2004) and the HAM. First, HAM computations are carried out explicitly on a yearly basis, directly providing return periods of practical interest. Second, HAM outputs can occur at any distance from the initiation of mass failure. Third, HAM outputs focus on deposit hazards rather than tsunami hazards. Fourth, slope stability is treated by a method of slices with a variety of failure plane shapes (Turner and Schuster, 1996). Fifth, gas hydrates influence slope stability in the HAM.

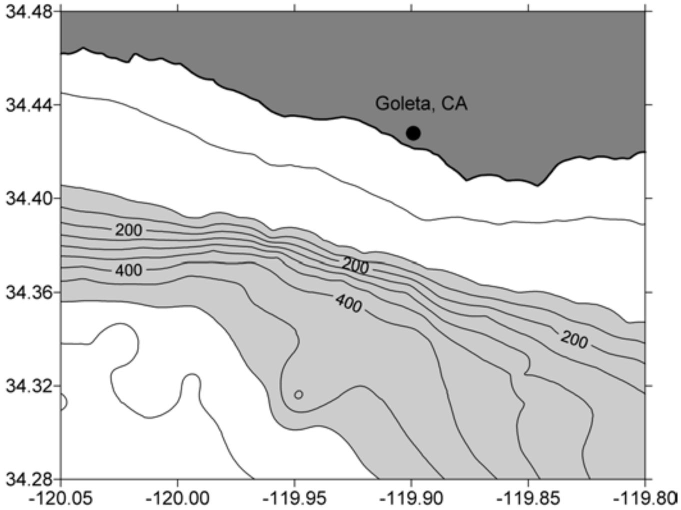

Fig. 1: Region offshore Santa Barabara, CA

Uses for Uncertainty

The slope conditions that trigger hazardous MTCs are found by running the HAM multiple times with randomized inputs. The HAM uses probability distribution functions to address geological uncertainty, with the understanding that these uncertainties may have a greater impact on sediment deposits than the errors in the slope stability or sediment motion models used. We demonstrate these ideas further below.

Random model inputs are meant to address geological uncertainty. The HAM also addresses epistemic uncertainty, or the differences among experts. Epistemic uncertainty is inherent to the current state of expert knowledge, which is distinct from geological uncertainty. Epistemic errors can be ascertained by running several different models and comparing the simulation results. This approach is not new, having been adopted by Syvitski and Hutton (2003) among others.

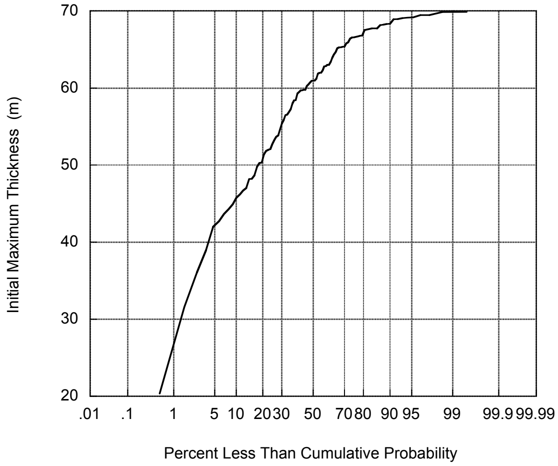

Fig. 2: Predicted MTC thicknesses

At every physical location in the HAM, probability distribution functions describe the sediment velocities attained and the sediment distances traveled. The probable structure of MTC deposits is formed over time. Because the HAM is specifically designed to inform risk analyses for offshore structures, it must first be shown to reproduce known deposits.

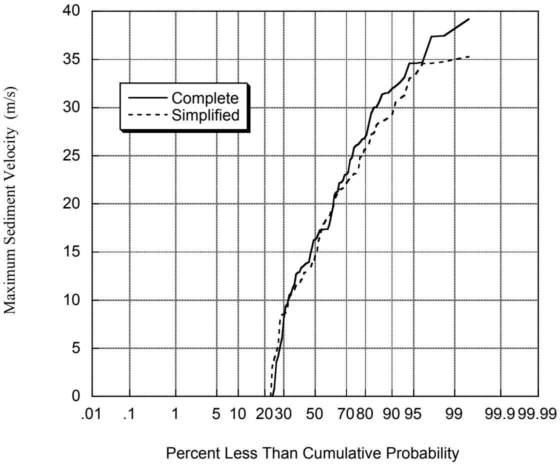

Fig. 3: Predicted MTC maximum velocities

Offshore Santa Barbara Results

We undertook a case study to compare seismic images of layered MTCs with results found by running the HAM. The chosen slope is off Santa Barbara, CA (Fig. 1). The probability of an earthquake of a given magnitude is provided by the Working Group on California Earthquake Probabilities (1995). We ran the HAM for 169,000 years and produced 95 MTC events, for a mean return period of every 1800 years. With a typical sedimentation rate of 4 mm per year, we can expect 7 m of sediment between each MTC event. The computed thicknesses in Fig. 2 indicate that MTCs favor a typical thickness of around 60 m in these sediments and on this slope. These values agree qualitatively with the recent work of Lee et al. (2003) and Greene et al. (2003). We estimate maximum sediment velocity using analytical models in this work for demonstrative purposes. We predict the maximum sediment velocity using a “complete” model given by Watts (1998) and a “simplified” model given by Watts et al. (2003). We find that 24% of MTC events undergo creeping motion. While the two probability distributions appear very similar, Fig. 4 shows that the correlation between the two velocity models is not favorable. We predict the maximum sediment runout using a “complete” model given by Watts and Waythomas (2003) and a “simplified” model given by Walder et al. (2003). Fig. 5 demonstrates the significant difference in results from the two models.

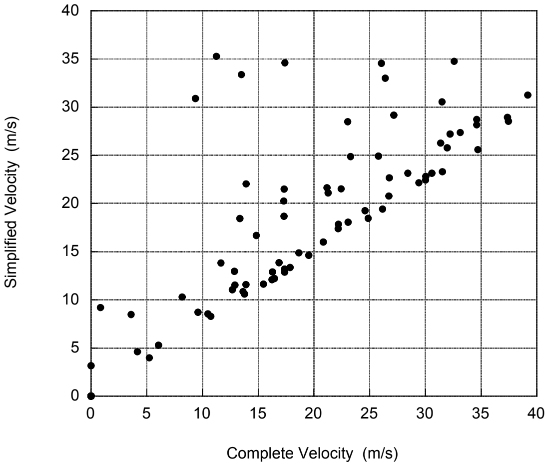

Fig. 4: Comparison of results from two velocity models

Discussion of Results

We compared HAM results with known deposits off Santa Barbara documented by recent marine surveys (Lee et al., 2003; Greene et al., 2003). The HAM results appear to be able to predict the deposit structure with reasonable accuracy. We did not find any significant difference in the probability distributions as a function of the stability analysis method used, which is apparently a common result (Turner and Schuster, 1996; Syvitski and Hutton, 2003). We also found that sediment center of mass motion is robust to different analytical models (Watts and Grilli, 2003). However, sediment runout appears to depend significantly on the chosen model. This means that some MTC structures are poorly constrained by existing models. Consequently, a random choice of model inputs and a random choice of models may be the only way to ascertain the realm of possible MTC hazards.

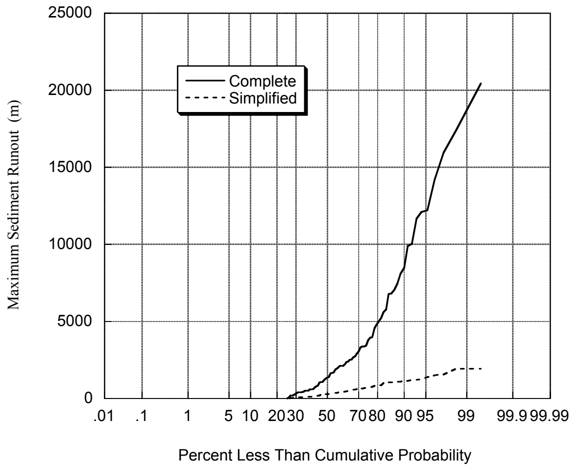

Fig. 5: Predicted MTC runout distances

Conclusions

A probabilistic model can describe the probability distributions of MTC hazards. Existing deposits appear to validate the HAM to the degree possible. The HAM reproduces deposit structures, and also identifies model inputs that are most likely to produce hazardous MTCs.

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