Factors Influencing Occurrence, Scale, Mobility, Runout, And Morphology Of Mass Movements On The Continental Slope

Homa J. Lee
U.S. Geological Survey, M/S999, 345 Middlefield Road
Menlo Park, CA 94025
650-329-5485 (phone) 650-329-5198 (fax) hjlee@usgs.gov

Award Number: N00014-01-F-0009
http://marine.usgs.gov/
Thrust Category: Marine Geotechnics

LONG-TERM GOAL

The goal of this proposal is an improved understanding of relationships between sedimentation, environment, and the morphology of continental slopes. Reaching this goal requires an understanding of how geotechnical and physical properties develop in marine sedimentary deposits on the continental terrace and how these properties influence sediment transport processes and the development of geomorphology. This goal will be accomplished through investigations within the northern California and New Jersey study areas and in the Adriatic Sea and Gulf of Lion regions in collaboration with European scientists partners through the EuroSTRATAFORM Project. The various components of this project are part of a concerted effort between the geotechnical groups at the USGS and Laval University. Their activities are very much interwoven but, for administrative reasons, annual reports are provided separately.

OBJECTIVES

Identify factors that can be mapped regionally and that determine where and how slope failures occur; derive a basis for producing regional maps that indicate relative landslide susceptibility. Model shear strength development with depth and incorporate this model into continental slope stability, post-failure behavior, and bedform processes. Observe and model pore pressure development in continental slopes. Analyze the relationship between seismic intensity, sediment instability and slope processes. Integrate these elements into geo-hazards assessments.

APPROACH

Our research focuses on the factors that lead to variations in the sedimentological and environmental conditions determining slope failure. We develop improved correlations between engineering classifications and strength factors. We relate compressibility, physico-chemical properties and strength to sediment microstructure, observed using SEM techniques. We simulate sediment accumulation in specially designed large cells. We measure sediment rheological properties in a viscometer. Geotechnical properties are related to sediment density state, obtained from detailed logs of downcore variability of sediment density and sound velocity. Basic strength parameters are obtained using triaxial drained and undrained tests and undrained cyclic tests. Using available bathymetry, and seismic profiles, we develop models for stability and mobility. Seismic shaking variations are evaluated probabilistically by seismologists. Pore pressures are either determined in situ by means of the Excalibur probe (AGC-Atlantic) or estimated using sedimentation rates and consolidation theory.

Pore pressures develop if there is charging by bubble-phase gas, or if earthquake shaking disrupts the sediment fabric and causes it to collapse with a resulting increase in the pressure of interstitial fluids. Driving stresses are balanced against strength variations in a Geographic Information System (GIS) to obtain a regional estimate of relative slope stability.

We also direct research towards identifying the morphological features that indicate slope failure and differentiate these from features that indicate the development of sediment waves or other strictly depositional processes.

Key individuals, at Laval: Jacques Locat, Jean-Marie Konrad, Serge Leroueil, Priscilla Desgagnés, and Marie-Claude Lévesque: strength and compressibility measurements, SEM studies, rheology measurements, and simulation of sediment accumulation.; at the USGS: Homa Lee, Kevin Orzech, Dianne Minasian, Brad Carkin and Pete Dartnell: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS.

WORK COMPLETED

During FY 02, a large proportion of our research efforts was directed towards satisfying the STRATAFORM objectives on the New Jersey Margin by completing a slope stability analysis of the Hudson Apron by various analyses using the SLOPEW package to investigate the potential role of gas hydrates and groundwater pore pressure on slope stability. This involved more advanced (triaxial tests, and SEM analyses) tests on various cores form the area. The testing has been done mostly on the 1999 Marion Dufresne cores. The analysis of the Hudson Apron rheological properties has been investigated and will be used as part of BING to simulate various conditions for debris flows along the slope of the Hudson. We also carried out, at the USGS during the summer of 2002, a series of cyclic simple shear tests in order to test the hypotheses that repeated cyclic loading results in a steady increase in shear strength with time. We performed these tests on Francisco Bay muds. This work was done in preparation for further tests on Adriatic Sea sediment samples to be obtained in FY03. These results were also shared with COSTA partners (including several EuroSTRATAFORM partners) at various conferences in North America and Europe

We collaborated with Syvitski, Parker, Orange, and Imran in recognizing and interpreting migrating sediment waves. We completed a paper for a special issue of Marine Geology that deals with migrating sediment waves. The paper includes empirical, theoretical, and laboratory results that show the mechanism of formation of these features and illustrate the ways to distinguish these features from submarine slope failures.

RESULTS

The completed (Desgagnés 2002) detailed slope stability analysis of the Hudson Apron sediments, mostly lying on a slope of 4° (see Figure 1 for the cross section analyzed), indicates that very high pore pressures are required to generate instability. The excess pore pressure required would be equivalent to a r_u (pore pressure ratio) value between 0.8 an d0.9, which at a depth of about 200m, would correspond to a pore pressure of about 150-1500 kPa. Causes which were investigated include: (1) under-consolidation, (2) groundwater seepage from a nearby coastal aquifer, (3) gas-hydrate decomposition, and (4) earthquake triggering. At this time, we believe that more than one cause is needed for the slide to take place. Advanced geotechnical testing of the Hudson Apron sediment indicates that they are normally consolidated, at least in the section investigated (*i.e.* to a depth of

38m). The rheological properties of the Hudson Apron sediment are quite similar to those of other sediment and follow the general relationship proposed by Locat (1997) for the liquidity index range tested between 1.3 to 3.5. As this STRATAFORM project is approaching an end, we put significant effort into completing major papers which were published, accepted in 2002 or are being completed. These include a review of submarine mass movements (Locat and Lee 2002) and a paper on sediment waves (Lee et al., in press). Our work on bioturbation and seismic strengthening was published in 2002 (Locat et al. 2002). Our overall findings were compiled and presented at the first EuroSTRATAFORM workshop in Winchester (UK) early in September 2002. We are also preparing for an upcoming cruise on the New Jersey margin (starting on September 26th) where cores will be collected using the GLAD800.

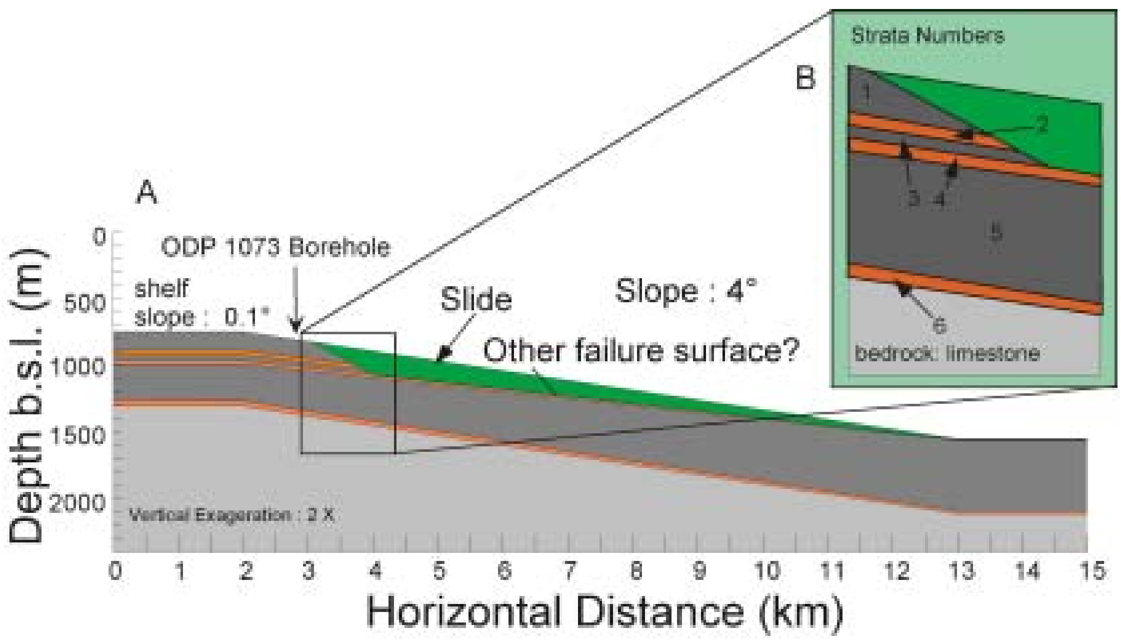

Figure 1. Hudson Apron cross section analyzed for slope stability (Desgagnés 2002, Locat et al. 2003, in prep.).

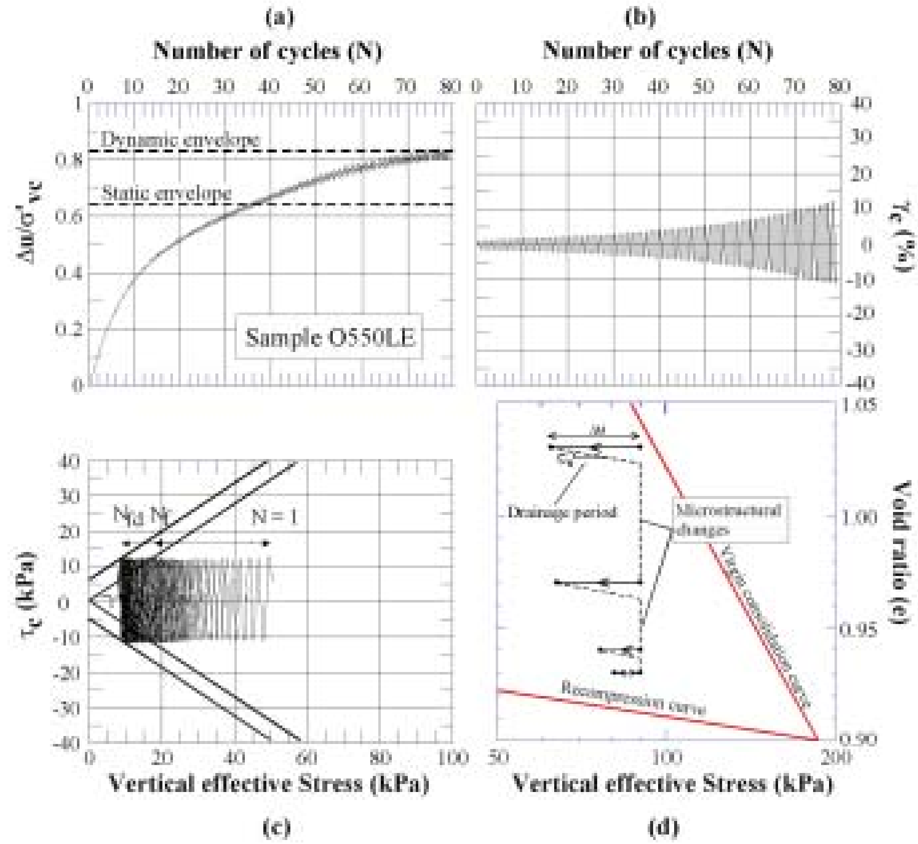

Figure 2. Seismic activity as a way of strengthening sediment (Locat and Lee 2002).

IMPACT/APPLICATION

Relationships developed in this project show the importance of sediment liquidity index and seabed density profiles in representing the behavior of marine sediment. These values can be used to predict regional slope stability and the rheological behavior of debris flows. General strength-density relationships can be used for modeling sediment accumulation and stability.

Reinterpretation of certain morphologic features as migrating sediment waves rather than submarine landslides has a significant impact on hazard assessment and models of continental slope deposition. Although both turbidity currents, which would need to be present to form sediment waves, and submarine landslides are hazards to offshore structures, they act differently on the structures and require different engineering considerations to mitigate their effect. Likewise, the presence of migrating sediment waves indicates the presence of turbidity currents or strong bottom currents, whereas submarine landslides can occur with sediment bodies deposited in a larger number of ways.

TRANSITIONS

Geoacoustic properties are being used by mappers and acousticians to identify lithologies acoustically. Rheological properties are being used by modelers to represent debris flows. Landslide generation models are being used by landscape evolution modelers.

RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin using many of the same techniques produced by STRATAFORM. Locat is investigating the behavior of a newly formed sediment layer acting as a natural cap over contaminated sediment in Canada. Locat, Lee, and a group of Canadian scientists and engineers have developed a project (COSTA Canada) to collaborate with the European COSTA (COntinental Slope STAbility) project. This will allow us to verify in other environments many of the concepts developed with STRATAFORM support.

REFERENCES

Desgagnés, P., 2002. analyse de la stabilité des pentes dans la région du Hudson Apron. M. Sc. Thesis, Department of Geology and Geological Engineering, Laval University, Québec, Canada, 85p.

Imran, J., Parker, G., Locat, J., and Lee, H., 2001. A 1-D numerical model on muddy subaqueous and subareial debris flows. Submitted to ASCE Journal of Hydraulic Engineering. 127: 959-968.

Locat, J., 1997. Normalized rheological behavior of fine muds and their flow properties in a pseudoplastic regime. *In: Debris flow hazards mitigation, mechanics, prediction and assessment*. Water Resources Engineering Division, ASCE, pp. 260-269.

Locat, J., 2001. Instabilities along Ocean Margins : A Geomorphological and Geotechnical Perspective. Marine and Petroleum Geology, 18: 503-512.

Locat, J., Lee, H., and Locat, P., 2002. Analysis of Submarine Mass Movements and its Implication for the Generation of Tsunamis, with a Particular Reference to the Palos Verdes Slide, California. Submitted to Marine Geology.

Locat, J., and Lee, H.J., 2002. Submarine landslides : advances and challenges. Keynote presentation, 8th International Symposium on Landslides, Cardiff, U.K., June 2000. Canadian Geotechnical Journal, 39: 193-212.

PUBLICATIONS

Desgagnés, P., 2002. analyse de la stabilité des pentes dans la région du Hudson Apron. M. Sc. Thesis, Department of Geology and Geological Engineering, Laval University, Québec, Canada, 85p.

Lee, H.J., Syvitski, J.P.M., Parker, G., Orange, D., Locat, J., Hutton, E.W.H., and Imran, J., In Press. Distinguishing sediment waves from slope failure deposits:field examples, including the 'Humboldt Slide,' and modelling results, Marine Geology.

Locat, J., and Lee, H.J., 2002. Submarine landslides : advances and challenges. Keynote presentation, 8th International Symposium on Landslides, Cardiff, U.K., June 2000. Canadian Geotechnical Journal, 39: 193-212.

Locat, J., and Sansfacon, R., 2002. Multibeam survey: a major tool for geosciences. Sea Technology, 43: 39-47.

Locat, J. Lee. H.J., Kayen, R., Israel, K., Savoie, M.-C., and BOULANGER, É., 2002. Shear strength development with burial in recent Eel River Margin slope sediments. *Marine Geotechnology and Resources*, 20: 111-135.

Urgeles, R., Locat, J., Lee, H.J., and Martin, F., 2002. The Saguenay Fjord, Québec, Canada: integrating marine geotechnical and geophysical data for spatial seismic slope stability and hazard assessment. Marine Geology, 185: 319-340.